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SCHOOL SCIENCE AND MATHEMATICS

Volume 110 • Number 1 • January 2010

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SSMA Official Journal of the School Science and Mathematics Association, Founded 1901

School Science and Mathematics

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School Science and Mathematics (Print ISSN: 0036-6803, Online ISSN: 1949-8594) is published in January, February, March, April, September, October, November and December on behalf of the School Science and Mathematics Association by Wiley Subscription Services, Inc., a Wiley Company, 111 River St., Hoboken, NJ, 07030-5774. Periodical postage paid at Hoboken, NJ and additional offices.

Postmaster: Send all address changes to *School Science and Mathematics*, Journal Customer Services, John Wiley & Sons, Inc., 350 Main St., Malden, MA 02148-5020.

Information for Subscribers: *School Science and Mathematics* is published in four issues per year. Subscription prices for 2009 are: Institutional Print & Online rate: US$250 (the Americas), US$250 (Rest of World), €180 (Europe) £153 (UK). Prices are exclusive of tax. Asia-Pacific GST, Canadian GST and European VAT will be applied at the appropriate rates. For more information on current tax rates, please go to www3.interscience.wiley.com/aboutus/journal_ordering_and_payment.html#Tax. The institutional price includes online access to the current and all online back files to January 1, 1997, where available. For other pricing options, including access information and terms and conditions, please visit www.interscience.wiley.com/journal-info.

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Production Editor: Alison McGonagle (ssm@wiley.com)

Electronic Access: This journal is available online at *Wiley InterScience*. Visit www.interscience.wiley.com to search the articles and register for table of contents and email alerts.

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ISSN: 0036-6803 (Print)
ISSN: 1949-8594 (Online)
Printed in the US by The Sheridan Group.

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Robert E. Yager, Hakan Akcay

The purpose of the study was to examine the effectiveness of the Iowa Chautauqua Professional Development Program in terms of changes in concept mastery, use of process skills, application of science concept and skills, student attitudes toward science, student creativity, and student perceptions regarding their science classrooms. Participants were 12 teachers who agreed to participate in an experimental study where an inquiry approach was utilized with one section and traditional strategies in another section. A total of 24 sections of students were enrolled in inquiry sections (365 students) and traditional sections (359 students). The data collected were analyzed using quantitative methods. The results are tabulated and contrasted for students enrolled in the two sections for each teacher. The results indicate that student use and understanding of science skills and concepts in the inquiry sections increased significantly more than they did for students enrolled in typical sections in terms of process skills, creativity skills, ability to apply science concepts, and the development of more positive attitudes.

The Role of Field Experience in Elementary Preservice Teachers' Self-Efficacy and Ability to Connect Research to Practice

Jacqueline T. McDonnough, Juanita Jo Matkins

Though the importance of including practicum experiences in programs for the preparation of elementary preservice teachers is generally accepted, the nature of these experiences on the development of skills in teaching science can vary greatly. This study compares the effect of variations in field experiences at two institutions, one which included a practicum that was not connected to the science methods course and instructor, and the other where the practicum was concurrent with and taught by the methods instructor. Interview data and results of the STEBI-B were collected across four years, with a total $n = 129$. The concurrent, embedded practicum yielded consistent increases in self-efficacy across the semesters. Also after the embedded practicum, preservice teachers showed greater understanding in research-based science teaching practices.

Attribution in Mathematics: A Review of Literature

Melanie L. Shores, Tommy Smith

This review of literature covers attribution studies in mathematics from 1974 through 2008. Thus far, mathematics education research in this area has been rather limited over the past few years. Attribution is discussed as it is defined by researchers, as being internal or external and its relation to mathematics achievement. In order for teachers to understand why or what is causing a student to fall behind academically, it is important that they start with attribution and whether or not it is being related to an internal or external factor. Therefore, it is imperative that new studies examine in more detail attribution from a teachers' perspective, and how this may impact the teaching and learning within their own classroom. This direction of the research could prove to be even more useful for preservice teachers as they begin their journey of teaching and dealing with student success and failure.

How Preservice Teachers Interpret and Respond to Student Geometric Errors

Ji-Won Son, Nathalie Sinclair

Recognizing and responding to students' thinking is essential in teaching mathematics, especially when students provide incorrect solutions. This study examined, through a teaching scenario task, elementary preservice teachers' interpretations of and responses to a student's work on a task involving reflective symmetry. Findings revealed that a majority of preservice teachers identified the student's errors from conceptual aspects of reflection rather than from procedural aspects. However, when they responded to the student's errors, preservice teachers tried to cope with them by invoking procedural knowledge. This study also revealed the three types of responses and two different forms of address by preservice teachers to student errors; these categories might provide insight into the difficulties arising in communication between students and teachers.

Research in the Classroom

Reflective Tutoring: Insights into Preservice Teacher Learning

Sheryl L. Stump

An undergraduate seminar was designed to help preservice teachers focus on students' learning. Preservice teachers planned and conducted weekly tutoring sessions with fourth graders and discussed their experiences in weekly discussions. The author investigated what preservice teachers learned about teaching mathematics from their focus on students' learning of mathematics. The author examined the tasks that preservice teachers posed to children, the questions they asked of children, and the reflections they wrote about their experiences. The article describes what the preservice teachers learned from their experiences, and provides insights into their knowledge and skills for developing children's mathematical power.

editorial

Gerald Kulm, *Editor*
Alan Zollman, *SSMA President*
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Sandi Cooper, *SSMA Executive Codirector*

A New Decade: A New Step Forward for the Journal

There is an old French saying, "That which is not moving forward is moving backwards." As the new decade begins, we are moving one big step forward with the publication of *School Science and Mathematics (SSM)*. *SSM* has been published independently by the School Science and Mathematics Association (SSMA) since 1901 as a hardcopy journal. Many libraries now only wish electronic copies of journals, and libraries also like similar journals to be "bundled." To continue the international prominence of our journal, SSMA needed to evolve.

After extended discussions over several years, the SSMA Board of Directors voted to contract with Wiley-Blackwell to produce and publish the *Journal*. This decision was based on the opportunity to join a highly respected publisher that brings greater visibility, wider readership, and increased prestige to the *Journal*. At the same time, service and costs to SSMA members will be maintained. The following are some frequently asked questions about this major move.

When will the change occur? With this January 2010 issue, Wiley-Blackwell has taken over the production and distribution of *SSM*. The *Journal* will be mailed to the members as before. The *Journal* will have a new cover, but the contents will continue to meet the historic quality that readers expect of the *Journal*.

Will SSMA continue control of the *Journal*? SSMA will maintain complete control of editorial policy and all key publishing decisions, including journal content, appearance, and pricing, and will retain full ownership of copyrights.

Will subscription rates change? Subscription rates for SSMA members will continue to be set by the SSMA Board of Directors. Wiley-Blackwell will set subscription rates for libraries and other institutions that better align with those rates set by other journals. A percentage of this anticipated increased revenue will return to the Association.

Will the contents of the *Journal* change? The current contents of the journal, including research articles and regular sections such as "Research in Brief," "Research in the Classroom," and "Problems," will continue.

Will the Editorial procedures change? The present editor and staff will continue until the end of the current editorial term in June 2011, when a new editor will be named. The editor will manage the submission, review, acceptance, and editing of manuscripts the same as in the past. Instead of doing page layouts in the editorial office and sending final copy to an independent press for printing and mailing, edited manuscripts will now be sent in Word format to Wiley-Blackwell for final editing, layout, printing, and mailing.

Will manuscript submission and review procedures change? The editor will now have access to *ScholarOne*, an electronic system for manuscript submission and review. This system will provide better communication with authors and reviewers on the status of manuscripts. New manuscripts will be submitted via *ScholarOne*, beginning January 2010. The current online system will be phased out over the next year as reviews and decisions of current manuscripts are completed.

What about access to the *Journal* online? In addition to the print copy, the *Journal* will now be published in full-text HTML and PDF via Wiley-Blackwell's electronic publishing platform. Members will receive hard copies of the *Journal* and have access to the electronic version as well. All members and institutional subscribers will be able to search *SSM* content, save search criteria, and set search alerts. In addition, Wiley-Blackwell will provide digitized journal content back to Volume 1, Issue 1. This new feature will provide researchers and educators around the world with more than 100 years of *Journal* scholarship.

We are looking forward to this new partnership with Wiley-Blackwell and the potential it offers for greater service to SSMA members and subscribers. The possibility to reach a wider audience and to offer electronic *Journal* access is a major step forward. As this transition continues, we will continue the traditional high standards of *Journal* scholarship and continue to seek ways to improve SSMA's outreach and impact on the science and mathematics education community.

The Advantages of an Inquiry Approach for Science Instruction in Middle Grades

Robert E. Yager
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Hakan Akcay
Marmara University

The purpose of the study was to examine the effectiveness of the Iowa Chautauqua Professional Development Program in terms of changes in concept mastery, use of process skills, application of science concept and skills, student attitudes toward science, student creativity, and student perceptions regarding their science classrooms. Participants were 12 teachers who agreed to participate in an experimental study where an inquiry approach was utilized with one section and traditional strategies in another section. A total of 24 sections of students were enrolled in inquiry sections (365 students) and traditional sections (359 students). The data collected were analyzed using quantitative methods. The results are tabulated and contrasted for students enrolled in the two sections for each teacher. The results indicate that student use and understanding of science skills and concepts in the inquiry sections increased significantly more than they did for students enrolled in typical sections in terms of process skills, creativity skills, ability to apply science concepts, and the development of more positive attitudes.

In the last decade, science as inquiry has become popular as a term for discussing science pedagogy, teaching, learning, and curriculum foci. Most science educators use the term, but many lack an understanding of what science inquiry is, what it looks like in the classroom, and the specific changes it requires in terms of instruction and an organizer for the curriculum.

Inquiry-based teaching is central to the National Science Education Standards (National Research Council [NRC], 1996) and the Benchmarks for Science literacy (America Association for the Advancement of Science, 1993). In both, inquiry is defined as an approach to teaching, the acts scientists use in doing science, and a way of dealing with the actual meaning of science. However, many teachers hesitate to teach science through inquiry or to use it as a new form of content because they did not learn in such ways during their preparation to become teachers. They too often merely mimic the teaching they experienced as students. Few have even had a personal experience with doing an inquiry on their own.

Inquiry can be a highly effective teaching method that helps students in terms of concept mastery and use of process skills. Because of this, it is often strongly recommended by state and national science standards. It exemplifies the very nature of current reform efforts. Unfortunately, there are few examples of the real meaning of inquiry that can be found in classrooms, textbooks, or course structures that characterize what occurs in actual science research laboratories. The Standards define inquiry as a:

> . . . multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries (NRC, 1996, p. 23).

Teachers have the most important role in stimulating student thinking. Guided inquiry often becomes giving hints, providing suggestions, giving veiled directions. When teachers know what they want students to demonstrate, they can often hinder them from real learning (or having a real experience with science). Too often, "guidance" is seen as "directions"! Teachers can/should encourage students to think about which of their ideas could provide possible

explanations. They must learn to ask new and more focused questions that require thought and analysis. They need to encourage students to formulate actual questions regarding objects and events in their own environments. Student questions should be used by teachers in developing pathways for learning — sometimes these may be very difficult ways for individual students; however, students should question their own "knowing." They should be curious to illustrate how they can deal with problems and the nature of things they do not "know"! Teachers must be "guides" while also being flexible in terms of the lessons they plan. There needs to be a positive correlation between inquiry methods and effective teachers (Anderson, 2002; Yager, Abd-Hamid, & Akcay, 2005).

Teachers are often unclear about the meaning of inquiry. This causes them to perceive inquiry as being difficult to implement in science classrooms (Wee, Shepardson, Fast, & Harbor, 2007; Windschitl, 2004). Most teachers think that inquiry is time consuming, that it costs too much, and that it is too advanced for their students (Bybee, 2000). Therefore, teachers must first understand what inquiry is themselves and then apply that knowledge, which can include using inquiry as a pedagogical tool (Wee et al.). One of the best ways to understand science as inquiry is through experience in classes, where scientific inquiry is practiced. Teachers can then help all their students understand science as a human endeavor that requires scientific knowledge and thinking skills that are important in their everyday lives (NRC, 2000). The Standards emphasize the importance of professional development programs that make students lifelong learners via their own inquiries. With this vision, teachers are professionals who take responsibility for their own professional development (NRC, 1996, 2000).

The purpose of this study was to determine the effectiveness of the Iowa Chautauqua Project as a model Staff Development Program for middle school teachers in Iowa. The enrolled teachers became more successful in promoting inquiry teaching during and following a yearlong workshop sequence beginning the summer of 2004 and then followed throughout the academic year till May 2005. The Chautauqua program is a professional development project designed to help science teachers develop their own learning processes through inquiry teaching and learning (Dass & Yager, 1999). The program was designed for in-service science teachers in grades K-12. However, the participants in this study were only from the middle grades. They worked together in cooperative learning groups to perform hands-on science inquiry activities that arose from participants' questions, curiosities, and experiences. The program emphasized learning science content using inquiry activities that are student-centered (actually proposed, planned, and carried out by students). Moreover, it focuses on a model for inquiry-based science instruction, with the teachers inquiring into their own teaching. The primary goal of the workshop was to increase the skills of in-service science teachers of science by indicating needed systemic changes in science instruction in the classrooms of all participating teachers. Teachers need to collaborate with both their students and with each other, as well as with school administrators, parents, and community leaders. The staff development program can be described with specific organizational features that include:

1. A two-week leadership conference for same of the most successful teachers from previous years who want to become a part of the instructional team for future workshops
2. A three- to four-week summer workshop at each new site for 30 new teachers electing to try inquiry teaching and learning strategies; the workshop provides experience with inquiry (teachers as students) and time to plan a five-day inquiry unit to be used as a pilot with students in the fall
3. A three-day fall short course for 30-50 teachers (including the 30 enrolled during the summer); the focus is upon developing a month long inquiry module and an extensive assessment plan
4. Interim communications with central staff, lead teachers, and fellow participants, via a newsletter, special memoranda, monthly telephone contacts, and school/classroom visits
5. A three-day spring short course for the same 30-50 teachers who participated in the fall; this session focuses upon reports by participants on their inquiry experience and the results of the assessment program. The emphasis is on sharing successes and failures while also planning more fall inquiry courses. Every attempt is to model inquiry teaching techniques by all staff members for the workshop. Active research projects are encouraged by staff members, teacher participants, and students in the classrooms of participants.

The Chautauqua program staff (including large numbers of lead teachers; i.e., the most successful inquiry teachers from previous Chautauqua

workshops) identified six important domains for developing instructional goals and areas for assessing successes over the 25 years of the Chautauqua efforts. These domains include:

1. Concept domain (mastering basic content construct)
2. Process domain (learning skills scientists use as they seek answers to their questions about the universe)
3. Creativity domain (improving quantity and quality of questions, explanations, and text for the validity of personal generated explanations)
4. Attitude domain (developing more positive feelings concerning the usefulness of science, science study, science teachers, and science careers)
5. Application domain (using concepts and processes in new situations)
6. Worldview domain (assisting students in understanding the nature and history of science and to practice its basic components, explaining, and events in the natural world (Enger & Yager, 2001; Yager & Akcay, 2007).

Methods

This study involved 12 teachers who agreed to collect pre- and postassessment information for all six assessment domains where one section was taught using traditional instructional methods were used, and one section where inquiry teaching and learning methods were used. A total of 724 students were involved in this study from 12 school districts. The Iowa Assessment Package for the Chautauqua Program was used to collect data (Enger & Yager, 2001). The package was developed and used annually to examine the effectiveness of the inquiry model for teaching science. It includes sample instruments, test features, scoring directions, and a wide variety of ways to assess student in terms of science in all domains (Enger & Yager, 2001; Yager, Blunck, & Ajam, 1990). The assessment handbook is reviewed, added to, and enlarged yearly.

A quasi-experimental design was used for this study. The same instruments were used as pre- and posttests. The pretests were given at the beginning of each inquiry module. The teachers then planned how to use the issues that were seen as personally relevant, current, and locally based to demonstrate using inquiry approaches for one group of students, while traditional (textbook) approaches were used in another section. The posttests were given at the end of each instructional period for each module (usually four to five weeks). The data were analyzed quantitatively by means and standard deviations. The differences in mean values were tested using *t*-tests.

Results of the Study

Table 1 indicates comparisons of pre- and posttest results in the concept domain for students in inquiry and textbook sections. Significant differences were found between pre- and posttest scores for student concept mastery in both inquiry ($t = 7.267$, $p < 0.001$) and traditional sections ($t = 4.591$, $p < 0.001$). This means that inquiry and traditional approaches to science instruction resulted in no statistically better ways of stimulating student growth concerning the mastery of basic science concepts. Perhaps it is most noteworthy, however, that students who experienced their science as inquiry were as successful as those who experienced science as a direct mastery of concepts identified in advance of instruction.

Table 2 indicates the results with an analysis of pre- and posttest results concerning the application domain. A significant difference was found between pre- and posttest scores for the application domain

Table 1

Mean and Standard Deviations for the Traditional and Inquiry Groups on Pretest and Posttest Scores in the Concept Domain

	Pretest		Posttest		*t*
	Mean	*SD*	Mean	*SD*	
Inquiry	17.50	3.62	36.83	5.42	7.267*
Traditional	7.83	4.71	35.17	7.96	4.591*

Note. Inquiry $n = 203$; traditional $n = 154$.
* indicates significance at $p < 0.001$ level.

Table 2

Mean and Standard Deviation for the Traditional and Inquiry Groups on Pretest and Posttest Scored in the Application Domain

	Pretest		Posttest		*t*
	Mean	*SD*	Mean	*SD*	
Inquiry	19.38	4.56	39.12	7.16	6.578*
Traditional	20.88	5.99	25.25	5.19	1.46

Note. Inquiry $n = 203$; traditional $n = 197$.
* indicates significance at $p < 0.001$ level.

($t = 6.578$, $p < 0.001$) in the inquiry sections. No significant differences were found between pre- and posttest scores for the application domain ($t = 1.46$, $p < 0.001$) in traditional sections. The results indicate that the inquiry students are far more successful in illustrating their abilities to apply concepts in new situations. The students in the traditional classrooms did not improve at all in their ability to apply concepts.

Creativity skills as defined by Torrance (1966) are closer to the definition of science that George Gaylord Simpson offered: "Science is an exploration of the material universe in order to seek orderly explanations (generalizable knowledge) of objects and events encountered: but these explanations must be testable" (Simpson, 1963, p. 82). The skills include frequency and uniqueness of questions, causes, and consequences concerning the report and observation of certain discrepant events. Tables 3 and 4 display the results of student growth regarding specific creativity skills prior to and following inquiry instruction, and compares them with results where students experienced their science in more traditional ways. The significance of the student growth between pre- and posttests for features of creativity in traditional textbook-oriented classes compared with inquiry-oriented classes are reported in Tables 3 and 4.

Table 3
Comparison of Pre- and Posttest Scores for Students in Concept-Oriented Sections Relative to Aspects of Creativity

Concept-Oriented Sections ($n = 314$)	Pretest		Posttest		t-Value
	Mean	*SD*	Mean	*SD*	
Questions	15.03	3.82	15.80	3.63	0.51
Unique questions	3.24	0.73	3.53	0.88	0.88
Causes	12.15	1.97	12.77	2.04	0.75
Unique causes	2.48	0.63	2.68	0.87	0.65
Consequences	12.57	2.10	12.82	2.38	0.27
Unique consequences	2.41	0.45	2.43	0.47	0.09

Note. Traditional $n = 314$.

Table 4
Comparison of Pre- and Posttest Scores for Students in Inquiry-Oriented Sections Relative to Aspects of Creativity

Inquiry-Oriented Sections ($n = 314$)	Pretest		Posttest		t-Value
	Mean	*SD*	Mean	*SD*	
Questions	15.34	4.00	31.68	7.43	6.71*
Unique questions	3.23	0.80	19.92	4.30	13.21*
Causes	11.33	2.67	22.68	4.10	8.39*
Unique causes	2.16	0.56	12.58	3.50	10.18*
Consequences	12.30	2.43	25.52	4.08	9.65*
Unique consequences	2.27	0.64	13.60	2.80	13.65*

Note. Inquiry $n = 314$.
* indicate significance at $p < 0.001$ level.

Table 3 shows comparisons of differences between pretest and posttest scores in textbook-oriented classes. There were no significant differences found between pre- and posttest for any of the features used to define creativity in textbook-oriented classes. The features consist of the total number of questions generated, the number of unique questions, the total number of causes suggested, the uniqueness of the causes suggested, the total number of possible consequences predicted, and the uniqueness of the consequences.

Comparisons between pretest and posttest scores in inquiry-oriented classes were compared. Table 4 indicates that significant differences were found between the pre- and posttest scores in the inquiry-oriented classes concerning all features of creativity. Students in the inquiry-oriented classes grew significantly more in terms of total number of questions generated, number of unique questions, total number of causes suggested, uniqueness of the causes suggested, total number of possible consequences predicted, and uniqueness of the consequences.

Table 5 indicates comparisons of pre- and posttest results concerning student attitude toward science in inquiry oriented sections versus the situation in textbook-oriented sections. Significant differences were found between pre- and posttest scores concerning student attitude toward science in inquiry-oriented sections for all four grades (6-9). No significant differences were found between pre- and posttest scores concerning student attitudes toward science in the traditional sections for all grade levels. Students in classes taught with inquiry-oriented instruction developed more positive attitudes toward science in all sections when compared with students in classes taught with a concept-oriented approach.

Table 6 indicates comparisons of pre- and posttest results regarding science process skills for students in inquiry-oriented sections versus those in a textbook-oriented section. Significant differences were found between pre- and posttest scores concerning understanding and use of science process skills in each grade from four through nine for inquiry-oriented sections. No significant differences were found between pre- and posttest scores concerning abilities to use science process skills for students in textbook-oriented sections. The results indicate that students in classes taught with an inquiry-oriented approach were able to apply more science process skills when compared with students in classes taught with a traditional textbook-oriented approach. Students in the inquiry sections grew significantly more in terms of their abilities to use selected science process skills in their classrooms. Students in the traditional textbook-oriented sections did not increase in their ability to recognize and to use such skills.

Inquiry materials and strategies enhance student skills with the use of science skills, as well as basic creativity skills, including questioning, suggesting causes, and predicting consequences. Certainly, these skill areas are related and may overlap. However, the value of inquiry seems to indicate a marked enhancement of student growth in these two domains.

Table 7 includes comparisons of student understanding about the nature and history of science between students in inquiry and textbook-oriented class sections. The results indicate that there are significant

Table 5
Comparisons between Pretest and Posttest Scores Regarding Positive Student Attitudes toward Science in Traditional and Inquiry Sections

Grade	Traditional Sections Mean			Inquiry Sections Mean		
	Pretest	Posttest	*t*-Value	Pretest	Posttest	*t*-Value
6	12.15	11.42	3.69	12.35	20.10	28.73*
7	10.57	10.41	0.53	10.90	18.10	27.02*
8	10.63	10.09	2.7	11.16	18.11	22.58*
9	11.17	11.08	2.95	11.65	19.42	25.94*

* indicates significance at $p < 0.001$ level.

Table 6
Changes in Pre- and Posttest Results Regarding Science Process Skills for Students in Traditional and Inquiry Sections

Grade	Traditional Sections Mean			Inquiry Sections Mean		
	Pretest	Posttest	*t*-Value	Pretest	Posttest	*t*-Value
4	2.65	2.60	0.1	2.70	4.68	7.21*
5	3.41	3.39	0.0	3.75	5.30	7.21*
6	5.10	5.05	0.0	5.06	6.84	7.22*
7	4.12	4.11	0.0	4.02	5.30	6.77*
8	5.00	5.11	0.0	4.97	6.51	6.78*
9	5.81	5.91	0.0	5.77	7.73	6.79*

Note. Inquiry $n = 59$; traditional $n = 54$.
* indicates significance at 0.001 level.

Table 7
Comparisons between Inquiry and Textbook Sections Related to Student Worldviews

Grade	Inquiry		Textbook		*t*
	Mean	*SD*	Mean	*SD*	
5	81.3	16.8	63.1	15.2	35.3*
6	84.1	20.1	64.6	17.3	42.6*
7	80.9	28.6	67.3	11.4	38.3*
8	81.4	18.3	67.8	18.9	40.0*
9	79.8	17.3	58.3	17.6	37.8*

Note. Inquiry $n = 276$; traditional $n = 246$.
* indicates significance at 0.001 level.

differences between students in inquiry- and textbook-oriented classrooms concerning their understanding of the nature of science in each grade from six through nine. Students in inquiry-oriented classrooms improve in their understanding of the nature of science to a greater extent than do students in textbook-oriented classrooms. Students in inquiry-oriented classrooms develop more appropriate views of nature and history of science when compared with students in classes taught with a textbook-oriented approach.

Discussion

The results of this study support the idea that when in-service teachers have engaging and direct experiences with inquiry-based learning themselves, they encourage more positive features that include the development of more positive attitudes of their students toward science and on their science teaching practices. It was interesting to note as well that teachers using inquiry-based learning experiences increased their confidence to teach even more inquiry-based science. All teachers indicated their plans to teach more science using inquiry modules for a whole year after the initial workshop experience.

In order to have successful student inquiry in science classrooms, teachers who are new to the ideas that define inquiry-based learning in science must invest the time necessary to become comfortable with the necessary understandings and abilities involved. Teachers need to have a deep understanding of the nature of science and how scientific inquiry leads to new knowledge. Teachers must have an understanding of what students need to know to be able to do to successful investigations — including many which their students identify themselves as interesting to pursue. These experiences are described as nine features needed for improved teaching offered in the National Science Education Standards (NRC, 1996, p. 52). Lastly, they need to understand what their roles are in managing an environment conducive to inquiry. Teachers who feel discomfort with the process can start with more structured investigations before proceeding toward full student-driven inquiries. However, the most important thing to remember is that there is

no formula for conducting science inquiries. There are many classroom activities that fall somewhere on the spectrum of inquiry, and teachers (and their students) must feel free to choose those that will be most successful in their own classrooms based on their own comfort with the subject and their prior knowledge and perceptions of their students, as well as the level of cognitive development characterizing their individual students. But it is also important that all teachers recognize and work toward the use of full and/or open inquiry.

Results of this study suggest that there is need for professional development programs to provide support for teachers during their implementation of inquiry approaches in their classrooms. The National Science Education Standards create a vision for teachers, which require substantive changes in how science is taught in K-12 education (NRC, 1996, p. 52). For this vision to become a reality, teachers must experience good science teaching in their professional development programs. Real reforms in science education will occur only, if teachers change their ideas about the meaning of science inquiry and their views of effective teaching (Yager, 1991). Teacher understanding of inquiry is a major part of the successful development of an inquiry oriented curriculum and the needed instructional strategies that are required for using it. Before student learning occurs and new curricula are developed, the intended curriculum should be understood and constructed in more general terms without exclusive concern for concept mastery characterizing most textbooks and classrooms. Teacher understanding is the most influential factor in this transformation (Aikenhead, 2000; NRC, 1996, 2000). Time, practice, and interactions among teachers and students are all needed.

Conclusions

The results reported in this study permit the following statements regarding the advantages of inquiry instruction as it is defined and practiced in Iowa by the most successful teachers enrolled in the Iowa Chautauqua Professional Development program.

1. Science concepts are mastered as well as they are with the more direct instruction commonly found in traditional classrooms. However, in some instances, students actually score significantly higher with respect to concept mastery while studying in an inquiry environment. This may be caused by increased performance and interest on the part of average and below average students — a phenomenon which should be researched further.

2. Student ability to apply concepts is enhanced significantly when science is experienced in an inquiry format.

3. Creativity skills are significantly enhanced by inquiry instruction. Students in inquiry sections were able to demonstrate their abilities to use creativity skills better than students in the traditional sections. These include increasing the total number of student questions generated, number of unique questions, total number of causes suggested, uniqueness of the causes suggested, total number of possible consequences predicted, and uniqueness of the consequences.

4. More positive student and teacher attitudes are enhanced by inquiry teaching. Student attitude, however, is much more positive when the teachers are more experienced and successful with inquiry approaches. The teachers involved with this study were experienced and successful with inquiry approaches; they were not first-time users of inquiry.

5. Process skills are developed to a significantly greater degree by students who experience their science with inquiry approach. Inquiry encourages students to use such skills themselves as opposed to using and practicing them in structured laboratories "to mimic what scientists do."

6. Students who study science as inquiry also develop better understanding concerning the nature and history of science.

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The Role of Field Experience in Elementary Preservice Teachers' Self-Efficacy and Ability to Connect Research to Practice

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Though the importance of including practicum experiences in programs for the preparation of elementary preservice teachers is generally accepted, the nature of these experiences on the development of skills in teaching science can vary greatly. This study compares the effect of variations in field experiences at two institutions, one which included a practicum that was not connected to the science methods course and instructor and the other where the practicum was concurrent with and taught by the methods instructor. Interview data and results of the STEBI-B were collected across four years, with a total n = 129. The concurrent, embedded practicum yielded consistent increases in self-efficacy across the semesters. Also after the embedded practicum, preservice teachers showed greater understanding in research-based science teaching practices.

Subject/Problem

Most elementary schoolteachers have minimal training in the sciences, but they are now expected to teach inquiry-based science so their students not only enjoy learning science, but also gain understanding of the nature of science, become skillful in the processes of science, and develop science literacy—all this while passing standardized exams. To do this effectively, preservice teachers need to be exposed to educational experiences that support critical reflection about science teaching and learning experiences that connect theory to practice. Research has shown that elementary teachers lack confidence or self-efficacy in their ability to teach science (Fulp, 2002). Given the connection between teachers' self-efficacy and their student's achievement, exploration of factors impacting preservice teachers' self-efficacy is critical to teacher preparation programs.

The focus of this research was to quantify and characterize the extent to which differences in the field experiences and involvement of the science methods instructor impact preservice teachers' self-efficacy and ability to connect theory to practice. Hudson and McRobbie (2004) recommended more research about the impact of field experiences on preservice teacher's ability to connect theory to practice. The two approaches were: (1) an embedded science methods practicum that occurred while students were taking the science methods course; and (2) a detached practicum that occurred one or two semesters after the science methods course. A science methods professor was the instructor of record for the embedded practicum, whereas the responsibility for supervising the detached practicum was either an adjunct instructor or the elementary mathematics professor.

In this article, the term "student teaching" refers to a specific culminating field experience where preservice teachers devote 10-15 weeks primarily to work in the school setting, including a 3-to-6-week period where these students have total responsibility for planning, teaching, and evaluating outcomes. Practica are defined in this article to mean the initial field courses where preservice teachers spend observing and performing limited tasks in a classroom. This experience may occur in conjunction with the methods course or separately. Both student teaching and practica are considered field experiences. For the purpose of defining conditions, field experience at Institution A was defined as "separate" to indicate an experience unconnected to the science methods course and at Institution B it was defined as "embedded" to indicate an experience coordinated with the science methods course and supervised by the science methods instructor.

Review of the Literature

The quality and quantity of science taught to elementary schoolchildren is strongly influenced by their teachers' confidence, attitudes, and knowledge level (Dana, Campbell, & Lunetta, 1997; Strawitz & Malon, 1986; Tippins, Tobin, & Nichols, 1995; West,

Watson, Thomson, & Parke, 1993). Thus, it is essential that preservice programs address the need to produce elementary teachers who possess strong *pedagogical content knowledge* (PCK). Shulman (1986, 1987) has described PCK as the transformation of content knowledge from the mind of the teacher into instructional practice. A teacher's PCK is in a constant state of flux as she progresses along the continuum from preservice experience into practice and beyond. Elementary preservice teachers may find teaching science a particularly daunting task because they are striving to gain science content knowledge in the process of also gaining instructional skills advocated by current reform efforts. These skills involve investigation and activity-based science instruction in inclusive classrooms, many of which face end-of-year high-stakes testing. Thus, the development of effective science PCK may be more difficult for elementary teachers today than ever before.

In the emerging paradigm, educating an effective teacher of science is coming to mean much more than presenting innovative ways to teach science in the context of the class meetings of a science methods course. Teacher educators recognize the need for field experience in teacher preparation programs (Tang, 2003; Zeichner, 2002). Ben-Peretz (1995) reported that field experience is viewed as the most critical factor in the development of teaching skills. Zeichner argued that it is not enough simply to place a student teacher in a classroom setting; the quality of the setting and the supervision and support provided are critical to the development of preservice teachers. Tang found critical facets across preservice teaching field experiences. In a study of a two-year sequence of field experiences, Tang found that relative levels of challenge and support drove the development of a sense of self as teacher, adding that "student teachers are more likely to have productive learning experiences by making cross reference of their student teaching experiences with what they learn in the campus-based component of the teacher education programme" (p. 496). Hudson and McRobbie (2004) argued that skillful mentors enhanced the quality of primary preservice teachers' experiences in the field. The mentors in their study were supervising or cooperating teachers, and the quality of the mentorship was based on the perceptions of preservice teachers. Hudson and McRobbie recommended further study of actual teaching practice in the context of the field experience. Recent research on the impact of field experience in developing effective teachers of elementary science clearly shows the necessity of field experience. What remains to be investigated is what constitutes a field experience that cross-references theory to teaching practice. This study examines preservice teacher perceptions of teaching practice in the context of their field experience.

The assessment of an effective teacher preparation program in science should include measurement of changes in the preservice teacher's level of PCK, which includes content knowledge, current pedagogical skills, and confidence in the ability to apply content and skills in the future, that is, self-efficacy beliefs. Self-efficacy beliefs are a teacher's judgment of her capability to bring about desired outcomes of student engagement and learning (Bandura, 1977; Tschannen-Moran & Hoy, 2001). According to Fulp (2002), elementary schoolteachers who evaluate their self-efficacy at teaching a variety of topics rank themselves as being least qualified to teach science. Given that studies have documented that strong self-efficacy beliefs are linked to high student achievement and increased student motivation (Henson, 2001), it seemed reasonable to investigate the impact of the science methods course and related field experiences on preservice teachers' self-efficacy.

Enochs and Riggs (1990) proposed that efficacy beliefs should predict science teaching behavior, and suggested that science teacher educators plan activities that improve the efficacies of elementary preservice teachers, including field experiences, peer teaching, and the self-evaluation of microteaching.

The development of an elementary teacher of science occurs over time and experience; it is a complex and intricate process. In 1977, Bandura proposed that it was in the early stages of the learning process that self-efficacy was the most malleable, suggesting that the experiences of preservice teachers were critical to their subsequent self-efficacy as practicing teachers. He further goes on to state that "efficacy expectation is the conviction that one can successfully execute the behavior required to produce the [desired] outcome" (p. 194). He explains the sources of information that influence self-efficacy or efficacy expectations. The primary source of information is performance accomplishment, which is based on the individual's performance of authentic tasks. An example of an authentic task for a preservice teacher would be teaching a lesson to elementary students. Vicarious experiences involve live and symbolic

modeling and because it is nonauthentic is a weaker source of efficacy information. This is analogous to the preservice teacher modeling a primary science lesson in the methods class. Verbal persuasion exposes the individual to suggestions, exhortations, and self-instructions that convey the message of "if I can do it so can you." Emotional arousal, the fourth source of self-efficacy information, can contribute either positively or negatively to efficacy as the individual tries to cope with a stressful situation. Observation of the preservice teacher by a methods instructor can be a source of emotional arousal. Furthermore, in a 1994 article, Bandura operationalized the experiences into four probable categories of support for change in self-efficacy: mastery experiences, vicarious experiences, social persuasion, and stress reduction. Brand and Wilkins (2007) used the four categories of Bandura as a framework for analysis of an elementary science methods course. They found evidence of interrelatedness of the categories, indicating that mastery experiences may support development of efficacy as a function of success with the other three categories as well as success as mastery experiences. The spirit of Bandura's definition of a mastery experience is embodied by the authenticity of the experience. Brand and Wilkins may be unduly optimistic in believing that mastery experiences among preservice teachers in a science methods classroom were indeed mastery experiences; the experiences they describe seem to fit better into Bandura's category of vicarious experiences. The nature of the methods class brings into question the possibility of authenticity and underscores the importance of including field experience and student teaching in a teacher education program.

Tang (2003) defined three facets of the student teaching context: action, socio-professional, and supervisory. Tang's somewhat narrower categories stemmed from the authentic nature of student teaching, which is less focused on vicarious experiences. Nonetheless, Tang's experiential constructs together provide a definition of mastery experiences in the context of student teaching, and thus, elaborate on Bandura's idea of mastery. The student teaching context provides the opportunity for additional support while engaging in a range of mastery experiences, usually accompanied by the support of a teaching supervisor, a classroom teacher, and consequent conferences with the supervisor and teacher. These congruent theories of Bandura (1977, 1994) and Tang provide a foundation for assessing the effectiveness of teacher preparation programs and assist in further characterizing the effects of differing field experiences.

Design

The goal of the study was to measure and describe the extent to which differences in the field experiences and the involvement of the science methods instructor impacted preservice teachers' self-efficacy and ability to connect theory to practice. The following research questions guided the study:

1. To what extent do differences in the supervision of field experiences affect the development of preservice elementary teachers' self-efficacy beliefs?
2. To what extent do differences in the supervision of field experiences affect the development of preservice elementary teachers' ability to connect research to practice?

The study used a repeated measure with intervention design (Green, Salkind & Akey, 2000). Student volunteers were administered an instrument to measure their self-efficacy before and near the end of the science methods course. A stratified purposeful sample of students was interviewed to probe for further information about the influence of the two different field experience approaches. Participants in the study were preservice teachers enrolled in graduate-level elementary education programs. Participants were students at two different public institutions of higher education in a Mid-Atlantic state, located within 50 miles of each other. Both institutions had Master's level elementary education initial licensure programs.

Both institutions employed on the faculty only one science educator who was responsible for both elementary and secondary science. The methods courses at the two institutions were very similar. Both science educators were students under the same science educator for their graduate programs, both received their doctorates at the same institution, and the educator at Institution A had been the teaching assistant in the elementary science methods course for the educator at Institution B. Ninety-seven students at Institution A and 44 students at Institution B were part of the study, which spanned six semesters. A total of 141 students participated in the study.

The primary difference between the two programs was the design of the practicum portion of the field experience. At Institution A, elementary education students acquired experience in the field by

completing two two-credit practicum courses. The second practicum for math, science, and social studies was done either concurrently or after the science methods course but prior to student teaching. There was no formal connection between the second practicum at Institution B and the science methods course. The primary science task was writing and teaching a learning cycle lesson. Students were supervised by either the mathematics methods instructor or an adjunct instructor. Students were graded by the university supervisor on the structure of their lesson plans and journal reflections.

At Institution B, elementary education students acquired experience with elementary science in the field by completing a science practicum course simultaneously with the elementary science methods course. There were three teaching assignments in the science practicum: (1) teach a science activity to a small group; (2) teach a learning cycle lesson to an entire class; and (3) teach a science circus (Matkins & McDonnough, 2004) to an entire class. The assignments could be taught in groups of up to three students. The student teacher(s) videotaped the learning cycle lesson and the circus, and presented a self-analysis with the video as a culminating project in the methods course. The methods instructor observed one of the three assignments and provided verbal and written feedback. The practicum course and the methods course were completed prior to student teaching.

Participants' self-efficacy beliefs were measured using the science teacher efficacy belief instrument (STEBI). STEBI was developed by Enochs and Riggs (1990) in response to Bandura's proposal that efficacy is content-specific, and that overall general self-efficacy does not necessarily transfer to specific knowledge, skills, and behaviors related to teaching. Enochs and Riggs used the teacher efficacy scale of Gibson and Dembo (1984), adapting it for science educators. Subsequently, Enochs and Riggs produced Form B for use with elementary preservice teachers (1990), and it has since been used extensively to measure preservice teachers' beliefs about teaching science (Cantrell, Young, & Moore, 2003; Moseley & Utley, 2006). Form B, named the STEBI-B, contains 23 items using a five-level Likert scale, with responses ranging from *Strongly Disagree* to *Strongly Agree*. Factor analyses have consistently shown that the two subscales of the STEBI-B, the personal teaching efficacy belief scale (PTEBS) and the science teaching outcome expectancy scale (STOES), measured different and distinct constructs (Enochs & Riggs, 1990; Cantrell, Young, & Moore, 2003; Moseley & Utley, 2006). An examination of the structural pattern of the items shows that all items in the PTEBS differ from all items in the STOES in that the PTEBS items are written in the first-person, e.g., "I know the steps necessary to teach science concepts effectively" and the STOES items are all written in the third person, for example, "When the science grades of students improve, it is often due to their teacher having found a more effective teaching approach." Figure 1 shows all the items in the STOES and PTEBS factors.

Questions have arisen about the second construct, the STOES and its usefulness as a predictor of teacher effectiveness. Studies have indicated that this construct may be more related to external locus of control beliefs than to self-efficacy beliefs, a possibility that is supported by the third-person pattern of the items in that construct. Tschannen-Moran, Woolfolk-Hoy, and Hoy (1998) clarified the distinction between efficacy and locus of control, pointing out that beliefs about whether a teacher can produce outcomes (efficacy) are different than beliefs that certain categories of actions affect outcomes (locus of control), adding that locus of control beliefs are weak predictors of efficacy. Also, in an analysis of the Gibson and Dembo instrument from which the STEBI-B was derived, Guskey and Passaro (1994) determined that the two factors in the parent instrument to the STEBI-B were separate dimensions, with the second factor related to perceptions outside the classroom, factors beyond the direct control of individual teachers, a conclusion that supports our question about the utility for education researchers of the STOES construct in the STEBI-B. If a factor used to measure the impact of teacher education programs is not predictive of later behaviors, then that factor is limited in its usefulness (see Figure 1). Despite questions about the use of the STOES construct as an efficacy measure, the other scale in the STEBI-B, the personal science teaching efficacy belief scale (PSTEBS) endures as a valid measure. In this study, the predictive ability of the instrument was important, and thus, only results from the PSTEBS were examined as a component of this study on elementary preservice teacher self-efficacy.

Preservice elementary teachers were administered the STEBI-B instrument to measure their self-efficacy at the beginning and near the end of the science

PSTEBS (Personal Science Teaching Efficacy Belief Scale)	STOES (Science Teaching Outcome Efficacy Scale)
1. I will continually find better ways to teach science.	1. When a student does better than usual in science, it is often because the teacher exerted a little extra effort.
2. Even if I try very hard, I will not teach science as well as I will most subjects.	2. When the science grades of students improve, it is often due to their teacher having found a more effective teaching approach.
3. I know the steps necessary to teach science concepts effectively.	3. If students are underachieving in science, it is most likely due to ineffective science teaching.
4. I will not be very effective in monitoring science experiments.	4. The inadequacy of a student's science background can be overcome by good teaching.
5. I will generally teach science ineffectively.	5. The low science achievement of some students cannot be blamed on their teachers.
6. I understand science concepts well enough to be effective in teaching elementary science.	6. When a low-achieving child progresses in science, it is usually due to extra attention given by the teacher.
7. I will find it difficult to explain to students why science experiments work.	7. Increased effort in science teaching produces little change in some students' science achievement.
8. I will typically be able to answer studentsí science questions.	8. The teacher is generally responsible for the achievement of students in science.
9. I wonder if I will have the necessary skills to teach science.	9. Students' achievement in science is directly related to their teachers' effectiveness in science teaching.
10. Given a choice, I will not invite the principal to evaluate my science teaching.	10. If parents comment that their child is showing more interest in science at school, it is probably due to the performance of the child's teacher.
11. When a student has difficulty understanding a science concept, I will usually be at a loss as to how to help the student understand it better.	
12. When teaching science, I will usually welcome student questions.	
13. I do not know what to do to turn students on to science.	

Figure 1. Two factors of the STEBI-B and the associated items from the instrument.

1. Tell me a story about you teaching elementary school.
2. Do you see yourself teaching science? Why or why not?
3. What experiences have you had so far that affected your sense of yourself teaching science?
4. How did your coursework affect your development as a teacher of science?
5. How important were your college teachers and supervisors in your development as a teacher of science?
6. How did your school placement affect your development?
7. Which experiences were the most important?

Figure 2. Questions used for interviews with preservice teachers at Institution A and Institution B.

methods courses at both institutions. In addition, students at each institution were selected for structured interviews. The students were selected to represent three levels of science course experience: minimal coursework (two undergraduate science courses), better coursework (three to four undergraduate science courses), and advanced coursework (more than four undergraduate science courses). Interviews were conducted prior to or early in the science methods course; after the science methods course; and at the end of the program, after student teaching. Interviews were conducted with three students from Institution A and five students from Institution B, for a total of eight students. There were seven interview prompts that guided all the interviews. The prompts are listed in Figure 2.

Analysis of the interview data for this study was accomplished using Tang's (2003) theoretical framework for the student teaching context. Bandura's mastery level was further deconstructed and defined within Tang's supervisory level. This study looked beyond the science methods classroom into the elementary science classroom, asking about the impact of supervision in authentic settings. Transcripts from the interviews were analyzed for references to

action, socio-professional, and supervisory contexts, as proposed by Tang. These categories were further defined by the researchers as follows:

Action: Hands-on experiences and/or practice in teaching science in the methods classroom or in the practicum, any practice teaching without feedback, including practice teaching elementary children *without socio-professional or supervisory feedback.*

Socio-Professional: Affirmatory feedback from self, classmates, cooperating teacher, university supervisor, or professor that is not judgmental or constructively critical, where *the feedback does not have a potential for being judgmental or constructively critical.* If self-feedback, the feedback can be internal as well as external, as in student reflections. For instance, feedback in a socio-professional context might be "That was GOOD!"

Supervisory Feedback: Feedback/oversight from self, classmates, cooperating teacher, university supervisor, or professor that is critical or has the potential to be. If self-feedback, the feedback can be internal as well as external. For instance, feedback in a supervisory context might be "You did a good job managing the activity and using wait-time." Supervisory *feedback is usually connected to specific pedagogy and has the potential to change practice.*

Three raters read the transcripts and analyzed them for the three categories. Interrater reliability was established through consensus building.

Findings and Analyses

Equivalency

Preservice teachers' total overall pretreatment scores on the STEBI-B instrument indicated positive feelings of science teaching efficacy (Institution A, 71.9% and Institution B, 74.6%). Analysis of the STEBI-B PSTEB subscale results indicated that the groups exhibited similar levels of science teaching efficacy beliefs at the beginning of the science methods course. As the sample sizes were unequal, thus violating the normality assumption, a Mann–Whitney U was conducted to compare the initial science teaching efficacy of the two groups. Results showed no significant difference in initial personal science teaching efficacy beliefs, $z = -0.453$, $p = 0.650$. Given the lack of significant differences between the two groups' initial PSTEB subscores, the assumption can be made that both groups shared similar confidence levels about their ability to teach elementary science.

Quantitative Results

Posttreatment science teaching efficacy beliefs as measured by the PSTEBS items for STEBI-B for the two groups revealed some interesting patterns in the data. Institution A's participants exhibited a significant decrease in their science teaching efficacy beliefs by the end of their methods course across two of the three years of data collection (see Table 1). These results indicated that the experience of the science methods course led to a decrease in confidence in ability to effectively teach science. In contrast, the posttest means for the PSTEB subscale increased for Institution B's participants across all semesters of the data collection period. In addition, a paired t-test comparing pre and posttest means of each annual group at Institution B indicated that their PSTEBS mean scores significantly increased in two of the three years (see Table 1). These results indicated that Institution B's participants' personal self-efficacies were positively impacted by aspects of their embedded field

Table 1
Preservice Teachers Personal Self-Efficacy Beliefs Subscale Paired Sample Means

	n	Mean pretest	Mean posttest	Mean difference	Standard deviation	t-value	p-value	Effect size
Institution A 2005	30	3.901	3.915	–0.708	1.115	3.477	0.002	–0.635
Institution B 2005	13	3.953	4.189	0.237	0.200	4.272	0.001	1.185
Institution A 2006	38	3.380	4.041	0.662	0.695	5.876	0.000	0.953
Institution B 2006	19	3.705	3.830	0.126	0.756	0.724	0.479	0.167
Institution A 2007	17	2.371	1.860	–0.511	0.443	4.762	0.000	–1.153
Institution B 2007	12	3.660	4.230	0.571	0.515	3.838	0.003	1.109

experiences. To gauge effect size, Cohen's *d* was calculated by dividing the difference of the means for each treatment by the standard deviation (Glass & Hopkins, 1996). The strong positive effect size results (see Table 1) for two of the three periods of Institution B groups' further support the contention that the field experience at Institution B, especially the connection of the methods class and practicum experience, positively influenced teacher self-efficacy.

Interview Results

Initially, the researchers analyzed the transcripts for the categories suggested by Tang. Three readers read each transcript and classified the interview responses as either action, socio-professional, or supervisory. Students at both Institution A and Institution B offered action stories, which are represented by the following two examples:

> I . . . taught about electricity and we did more group work type stuff. I gave each group the materials. . . . I just said, "Here, make it work" . . . , so it was really fun. They enjoyed it, they really, really had a good time. . . . They had a great time; they really enjoyed it. [Brenda, Institution A]

> We were teaching them about the bones in their body, so we were using pasta. . . . And so then they had to start to explore on their own. . . . I led the explanation and so it was—it was a lot of fun, it was so much fun being in a kindergarten and getting their attention, and it was—I can't wait to have my own classroom, I guess is the biggest thing. [Dawn, Institution B]

The action stories from Institution A and Institution B reflected student teachers who were enthusiastic about teaching science and about working with elementary children, both characteristics essential to future success as an elementary teacher of science. The students at Institution B also included specific references to practical strategies for managing the development of concepts. In the example given by Dawn, she referred to exploration and explanation, two of the components of the learning cycle. Though the major assignment for students in the practicum at Institution A was planning and teaching a learning cycle lesson, no references were made in any of their interviews to a specific stage of the learning cycle.

Socio-professional responses came from experiences in both methods classes and also in both practica.

> She [the professor] would present lessons or present information and we would have to be able to explain everything behind it, like why we think this way, or the group had to be able to encourage the students to explain why instead of just giving a black and white answer. [Brenda, Institution A]

> It was the first time I was up there in front of the room teaching and the kids were really engaged and they ended up with such good questions and wondering about different things, like how long do you think the reaction will take place, and could we measure it, and all these really good science-y questions, and it made me feel more confident about being a teacher. [Emily, Institution B]

The students at Institution A examined science concepts in the context of the methods classroom, and were supported in doing so by their classmates and the professor, a strategy designed to reduce stress while increasing fluency with science concepts. Students at Institution B also explored specific science concepts as a component of methods class activities, and extended their fluency by teaching these concepts in elementary classrooms.

Responses that could be categorized as supervisory occurred more often in Institution B where the practicum was concurrent and the professor worked with students in their practicum placements. During their practicum, the science methods instructor supervised the development of the learning cycle lesson and the science circus, observed one of the science lessons in the school setting, and held a postteaching conference with the preservice teacher(s) and sometimes the classroom teacher. Nonetheless, students from Institution A had had supervisory experiences related to their science assignments in their practicum, though the supervision was usually self/internal. The following excerpts are responses from both Institution A and Institution B.

> For my practicum B I taught in a fifth grade classroom, and I taught a science experiment on sound and it was . . . complete chaos, but it worked out pretty well. So, it was a positive experience; I feel like I learned a lot from it. It's kinda weird having a teacher, like, watch you when you were just with the kids, but that was probably my favorite lesson I've done so far. [Anne, Institution A]]

> I like the fact that the practicum teaching things are not graded. It's literally, did you do it or didn't you. And whether you went in there and tried and looked back and tried to figure out, what could I have done better, what could I have done more for these kids, and that I think was the biggest thing. [Dawn, Institution B]

Analysis and results showed that students at both institutions valued their experiences in classrooms. This excerpt from Anne at Institution A indicates a general sense of satisfaction with a specific experience teaching a science lesson on sound. Her critique of her own teaching stops short of asking what could be done about the "chaos," as she put it, of the lesson. In contrast, Dawn at Institution B emphasized self-criticism, with an implied expectation that the lesson could be improved. Anne's reference to external supervision, "it's kinda weird having a teacher watch you," provides no reference to a productive interaction between the teacher and Anne at the time of the lesson, nor is there recognition that the classroom teacher might have provided valuable support and insight into reducing the sense of "chaos" and perhaps into how Anne could have "done more for these kids," as Dawn commented. Anne's retelling of her experience is centered on her satisfaction and perceived success. Though Dawn is pleased that the practicum assignments were ungraded (a practice purposefully designed to reduce stress), she also emphasizes the context of student outcomes and her commitment to figuring out what she could do to achieve better outcomes.

Interview results indicated that the embedded field experience at Institution B during the science methods course led to a greater sense of self as teacher. This was perhaps because of the richness of experience with Tang's three contexts of field experience (2003), action, socio-professional, and supervisory, that were components of the embedded field experience during the science methods course. The embedded practicum involved action—e.g., students were required to teach science lessons to elementary children in small group and whole class settings; socio-professional—e.g., students collaborated in planning and teaching with their classmates, their classroom teachers, and their university professors; and supervisory—e.g., students participated in a postteaching conference where they and their supervisors evaluated their performance. Though there was no formal interaction of the science methods instructor from Institution A during the practica, the science methods instructor was sometimes contacted by individual students to review lesson plans or borrow equipment to teach the lesson.

Conclusion and Contributions

Results of the study supported the practice of embedding field experience with the science methods course in addition to the concentrated student teaching experience that is common practice in teacher education programs. The fact that self-efficacy as measured by the PSTEBS increased only with the embedded field experience supports the importance of the field experience that is supervised by content experts such as the science methods instructor. Also, the participation of the methods instructor in the field experience seemed to support connections of research to practice, as seen in the references to aspects of the learning cycle (engage, explore) in the retelling of science practicum teaching experiences. Elementary preservice teachers have particular difficulties with science content. The additional practice and support of a faculty-supervised science teaching experience coupled with instruction in a science methods class creates a dynamic relationship between theory/pedagogy and classroom practice. This combination supports the efforts of the preservice teacher in teaching potentially difficult science content. It also provides the opportunity for just-in-time feedback on reform-based aspects of science instruction such as teaching about the nature of science. Timely feedback may be critical given Bandura's characterization of mastery experiences while the novice is still malleable. At Institution B, the science methods instructor played a significant role in supporting the preservice teachers' self-efficacy development because she had the opportunity to give feedback at multiple points. Her observation of the group science circus (Matkins & McDonnough, 2004) inquiry lesson and review of the lesson reflection and videotape provided occasions to reinforce and/or to correct the preservice teachers' classroom practices. This relationship allowed the preservice teacher ample opportunity to practice specific instructional methods and to receive timely feedback from the faculty supervisor. Having that knowledge lent itself to an increase in personal science teaching confidence on the part of the preservice teacher. The science methods instructor's contacts with the preservice teacher during the field experience takes on an added significance when viewed in light of Bandura's

categories of experiences that support change in self-efficacy. Of particular interest to this study is Bandura's (1977) "performance accomplishment," one of the sources of self-efficacy information. Performance of tasks during the field experience allows the preservice teacher to have "practical personal experience" (Bleicher, 2007) that contributes to the development of self-efficacy. The involvement of the science methods instructor with the embedded field experience at Institution B provided those preservice teachers additional supervisory experiences (Tang, 2003), which reinforced their "performance accomplishment," thus leading to greater increases in self-efficacy than the participants at Institution A.

Tang's categories (2003) were developed in the context of field experience, and they provide a framework for examining how Bandura's ideas can be expanded. The action and socio-professional categories described by Tang are very similar to Bandura's categories, but Tang added a supervisory category that is not explicitly addressed by the four categories of Bandura. It may be that in considering the supervisory category, the crucial difference can be seen between Institution A and Institution B's approach to the development of elementary science teachers. At Institution B, not only did the science methods instructor supervise, observe, and provide feedback on the field experience, but students themselves were trained to reflect and critique their own teaching in the context of the support of the methods course. Feedback was provided by the instructor both on their teaching and on their ability to critically reflect on their teaching. The mastery experiences at Institution B were situated in the field, and were more authentic to the future context of classroom teaching than at Institution A. Furthermore, the experiences involved meeting the complex demands of school culture, including class schedules, matching instruction to standards, and adapting to the physical configurations of classrooms. The consistent improvement in efficacy across semesters of the students at Institution B provides further support for the contention that closely linking the science methods course to field experience is an effective strategy for preparing elementary teachers of science. The decrease in self-efficacy at Institution A, along with the interview results, indicates that without supervision of the content and pedagogical expert, mastery is questionable. These results suggest that authenticity of the performance situation is critical but more is needed for mastery experiences. In this study, the variable that seems to be the causal factor for mastery was the interaction of the science methods instructor at Institution B in the embedded field experience.

Implications

Although study findings pointed to the value of embedding field experiences for elementary preservice teachers, there are several issues that forestall this as a widespread practice. Nonetheless, the effect size and the interview results showing the importance of the mastery experience recommend a review of existing field experience practices. In medium-sized teacher preparation programs with 50 to 75 preservice teachers engaging in practicum and student teaching each semester, providing traditionally supervised field experiences can be prohibitive given the number of program faculty. With one science methods instructor on faculty, the logistics of classroom or video observations can be daunting. Institution A currently finds itself in this position. Practicum students are overseen by an elementary mathematics specialist with adjunct instructor status and student teachers are supervised by retired elementary teachers with university supervisor status. The results of this study support the exploration of other strategies that have the potential to provide rich, context- and content-specific, supervisory support.

If as in many cases the science methods instructor cannot participate directly in supervision of field experience, institutions could implement training protocols for those personnel, adjunct or otherwise who have that supervisory responsibility. This training should go beyond general classroom pedagogical strategies and be rich in science best practices. With such training, the network of effective supervisors could be expanded without placing excessive demands on the science methods instructor.

One area for further study is the use of cyber-enabled technologies. Groups of preservice teachers and science pedagogy-trained university personnel can interact using Internet-based technologies to examine, comment, and acquire feedback about their classroom practices and challenges. Such an arrangement exposes preservice teachers to supervisory and socio-professional feedback which provides the type of support that promotes development of their sense of self as teachers. This conclusion is supported by Tang's (2003) research of the impact of field experiences and Bandura's (1977) work on the importance of mastery experiences on preservice teachers'

development as teachers. Interaction with peers and a science-pedagogy expert provides the preservice teacher opportunities to make direct connections between their experiences in the field and their methods coursework. New Internet communication tools such as Wikis and blogs could serve to connect methods instructors and their research expertise with both preservice teachers and their supervisors. Blackboard, an Internet course-delivery program used by many universities, now provides multiple options for student/instructor interaction. Face-to-face telecommunication is becoming increasingly feasible with the assistance of free programs such as Skype.

For elementary science instruction to conform to current goals in science education, teachers must successfully connect activities to content, incorporate lessons that develop skills in the science processes, and explicitly connect experiences to the nature of science, all in the context of inquiry-based instruction. Even with the support of sophisticated and increasingly user-friendly communication technologies, university faculty cannot serve as primary mediators overseeing the transfer of research to practice. Supervisors of field experiences and student teaching must collaborate with methods instructors to facilitate the translation of those practices taught in the methods classrooms to actions in the field. Not only will this collaboration benefit the student, but it will also shape the approaches used by both the methods instructor and the supervising adjunct. Without such collaboration, the gap will not narrow between the theories emphasized in methods courses, such as constructivist learning and inquiry-based teaching, and the practices that are common in schools, such as activities with little connection to content.

The findings in this study shed light on the importance of the practicum experience in the development of preservice elementary teachers' self-efficacy and their potential success in the classroom but raise several other questions for additional study. One question raised is the effect of combining content areas in a practicum, such as the practicum for Institution A which combined mathematics, social studies, and science. Does this practice dilute the ability of the supervisor to provide specific content feedback to the preservice teacher? Also, what is the optimal timing of feedback? Could expert feedback during student teaching or even in the first year of employment as a teacher provide the supervision necessary to support mastery of elementary science teaching? Is it possible that current practices in mentoring new teachers could be refined to provide such supervision?

The context of this study was the science methods course and the associated practicum experiences and supervision. Though an elementary preservice is a generalist, teaching all the core content areas, is there justification for requiring four separate methods courses and specifically dedicated practica for each content area? School divisions characteristically provide in-service support in elementary reading, language arts, and mathematics. The areas that tend to be neglected are social studies and science. Without sufficient and skilled training during their teacher education program, elementary preservice teachers may never understand what it is to teach science well.

Given the connection between teacher self-efficacy and student achievement levels (Henson, 2001) and our findings linking self-efficacy to embedded field experiences, finding answers to questions concerning optimum field experiences is of value to the science education community.

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Attribution in Mathematics: A Review of Literature

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This review of literature covers attribution studies in mathematics from 1974 through 2008. Thus far, mathematics education research in this area has been rather limited over the past few years. Attribution is discussed as it is defined by researchers, as being internal or external and its relation to mathematics achievement. In order for teachers to understand why or what is causing a student to fall behind academically, it is important that they start with attribution and whether or not it is being related to an internal or external factor. Therefore, it is imperative that new studies examine in more detail attribution from a teacher perspective and how this may impact the teaching and learning within their own classroom. This direction of the research could prove to be even more useful for preservice teachers as they begin their journey of teaching and dealing with student success and failure.

The most dangerous, yet most persistent myth associated with mathematics education is that "success in mathematics depends more on innate ability than on hard work" (National Research Council [NRC], 1991, p. 10). Given the historical doubts regarding the intellectual ability of minorities and females, it is not surprising that society has come to agree with the myth that "females and members of certain ethnic groups are less capable in mathematics" (NRC, p.11). However, in order to construct a secure mathematics channel for female, minority, and other students, such misconceptions must be overcome. Therefore, there seems to still be a need to examine factors that affect mathematics achievement for these groups of students. In particular, there is a need to further examine attribution and how it impacts the learning and success of mathematics.

This review of literature covers attribution studies in mathematics from 1974 through 2008 (see Table 1). However, only three studies since 2000 were found, one of which is by the present author (Shores & Shannon, 2007). Hence, there appears to be a need to continue research on attribution, which is important to the success of students in mathematics. More specifically, in order to increase success in mathematics for girls and minorities, it is imperative that researchers and teachers understand what is causing these students to fall behind. This starts with what they attribute success and/or failure to and what is considered actual success for them. While the following studies define what attribution is and causes of success and/or failure, they have fallen short in providing practical information for the regular classroom teacher. With new studies, research could provide evidence as to whether or not teachers are aware of their own attributions and how their own attributions could impact their approaches to teaching mathematics. Awareness of student attributions could prove useful in assisting preservice teachers and how they deal with students in the classroom regarding success and failure.

Background

What Is Attribution?

According to attribution theory, individuals attribute their successes and failures to either internal or external causes (Dweck, 1986; Weiner, 1974). Individuals who are internally motivated attribute their success to ability or effort and take personal responsibility for their performance. On the other hand, individuals who are externally motivated attribute their success to factors outside of their control, such as luck or task difficulty (Powell & Caseau, 2004).

Attribution researchers (e.g., Frieze, 1976; Frieze & Snyder, 1980; Weiner, 1985) have identified ability and effort as perceived causes of individual success or failure. Success is often seen as the result of personal competence, whereas failure can be overcome by effort. Ability can be characterized as consisting of aptitude and learned skills, while effort is the level of exertion applied to a situation, either temporarily or over time (Weiner, 1979). These principles can be applied to classrooms when a teacher wants to explore a student's classroom performance, and, more specifically, female and minority student performance, in order to increase his or her academic success.

Internal or External Attribution

The founding father of attribution theory, Fritz Heider, is credited with the notion that to understand why someone behaves as he or she does, we must first

Table 1
Summary of Attribution Literature

Attribution subheadings	Author and date(s)
What is attribution?	
	Dweck (1986)
	Frieze (1976)
	Frieze and Snyder (1980)
	Powell and Caseau (2004)
	Weiner (1974, 1979, 1985)
Internal or external attribution	
	Abramson, Garber, and Seligman (1980)
	Ames and Lau (1982)
	Covington (1992)
	DeBoer (1985)
	Nelson-LeGall (1985)
	Peterson and Barrett (1987)
	Schunk (1982)
	Schmitz and Skinner (1993)
	Schunk and Gunn (1985)
	Stage, Muller, Kinzie, and Simmons (1998)
	Weiner (1979, 1986, 1992)
Attribution and mathematics	
	Bandura (1981)
	Cobb, Wood, Yackel, and Perlwitz (1992)
	Frieze (1980)
	Gore and Roumagoux (1983)
	Harari and Covington (1981)
	House (2006)
	Kelley and Michela (1980)
	Levin (1992)
	Nicholls (1978, 1984)
	Peterson et al. (1985)
	Platt (1988)
	Shores and Shannon (2007)
	Tennen and Herzberber (1985)
	Weiner (1974)
	Wentzel and Wigfield (1998)
	Wolleat, Pedro, Becker, and Fennema (1980)

establish the causality of the behavior as internal to the individual, external in the environment, or both (Stage et al., 1998). Females are more inclined to draw negative conclusions about their ability and are more debilitated after failure than other students (Stage et al.). An individual who believes both that ability is responsible for past success and that ability is a stable trait will most likely expect success on similar tasks in the future (Weiner, 1979, 1986). Expectancy of future success may be somewhat reduced, however, when previous successes are attributed to effort, because most people perceive effort to be a variable trait. When failure is attributed to stable, uncontrollable causes such as ability, it is frequently accompanied by a low sense of self-efficacy, and motivation is diminished because future performance cannot be expected to improve (Abramson et al., 1980; Schunk, 1982).

Continual attributions of failure to stable, uncontrollable factors can also lead to the reduction of effort in challenging tasks (Weiner 1986, 1992), unproductive strategies for seeking academic help (Ames & Lau, 1982; Nelson-LeGall, 1985), the adoption of passive coping strategies (Peterson & Barrett, 1987), and reduced intentions of pursuing further coursework in the academic area of failure (DeBoer, 1985). When failure is attributed to unstable or controllable causes, such as insufficient effort, students do not usually believe that future failures are inevitable.

Research empirically verifies that students who attribute failure to low effort are more likely than students who attribute failure to controllable or invariant causes to maintain high expectations for future successes (Stage et al., 1998). In some situations, particularly at the lower grades, trying hard, even when a student fails, can benefit a student because teachers' evaluations of a student's performance following failure are often softened by a show of effort. Procrastination and spreading oneself too thin are other examples of self-handicapping strategies that can lead to failure "with honor" — or at least one without disgrace (Covington, 1992). Continually attributing failure to unknown causes may be most damaging of all because doing so indicates a global sense of confusion and loss of control over outcomes. Such conditions may lead to disaffection in the classroom and academic failure (Schmitz & Skinner, 1993).

Another study (Schunk & Gunn, 1985) explored how children's self-efficacy and skill development were affected by their attributions for task successes and how task strategies influenced attributions.

Attributional theories postulate that individuals make causal ascriptions for the outcomes of their actions. In school, students often attribute their successes and failures to ability, effort, task difficulty, and luck. Future expectancies of success and failure depend heavily on causal ascriptions. For example, if one believes that the conditions surrounding a task will remain much the same, attributing prior successes to relatively stable causes, such as high ability or low task difficulty, should result in higher expectancies of future success than attributions to the more unstable causes of high effort or good luck.

Attribution and Mathematics

House (2006) reported that students who felt that success in mathematics in school required memorizing the textbook or notes and good luck were more likely to have earned lower algebra test scores. In addition, two self-belief variables (mathematics is not one of my strengths and success in mathematics at school requires memorizing the textbook or notes) showed significant negative relationships with algebra knowledge. Students who attributed their success in mathematics at school to external factors (such as good luck) tended to earn lower algebra test scores, while students who reported that they enjoyed learning mathematics tended to show higher test scores.

Wentzel and Wigfield (1998) indicated that students who attribute their academic success outcomes to external factors tend to show lower achievement than students who attribute their success to factors they believe are internal or that they control. Students who attributed their success in mathematics at school to good luck tended to show lower algebra test scores. Consequently, students who felt that external and uncontrollable factors (good luck) were needed for mathematics success at school also tended to show lower test scores. Hence, the question that still remains unanswered for teachers and researchers is that of what we can do to change attribution from external to internal.

There have been many efforts to predict academic performance or "success" in mathematics using achievement (Medical School Admissions Test, etc.), previous performance indicators such as Grade Point Average (GPA) and demographic data (gender, socio-economic status, age, etc.), but of more practical interest are predictors that can be manipulated or modified so that the individual has a better chance of academic success. Platt (1988) found that the specific attribution of "ability" for high school success had a positive effect on academic self-concept and the specific attribution for success of "effort" has a positive effect on both academic self-concept and effort in college courses. This review (Platt) of the literature suggests that there is no consensus about which approach to take and all approaches have met with limited success.

Platt (1988) also notes that while attributions for success were predictors for performance in females, males' confidence in learning mathematics, and self-predicted grade were the best predictors for course grade. Higher grades were related to a strong mastery orientation, defined as attribution for success to effort or ability and attribution for failure to task difficulty or luck. A cause is classified as global if it affects many areas of one's life, and is classified as specific if the cause is restricted to a particular setting ("I have trouble with all tests" vs. "I do poorly on math tests"). Those who attribute failure to internal-stable-global causes have a pessimistic attributional style, and are more likely to display symptoms associated with learned helplessness, such as not trying when faced with failure. Those who attribute failure to external-unstable-specific causes have an optimistic attributional style and are expected to continue to work in the face of failure.

The Attributional Style Questionnaire (ASQ) (Peterson et al., 1985) was developed to measure attributional styles along the three dimensions described above: internal/external; stable/unstable; and global/specific. The ASQ is a self-report measure "of patterns of explanatory style', which is the tendency to select certain causal explanations for good and bad events" (Tennen & Herzberber, 1985, p. 20). Those students with an optimistic attributional style are predicted to be more successful in course performance and to feel less frustrated while working on assignments. Tennen and Herzberber examined the specific causal attributions (ability, effort, luck, and task difficulty) for course performance, and how they are interpreted by the students in an attempt to discover their relationship to course performance and feelings of frustration.

Tennen and Herzberber (1985) found significant correlations between final grade and the attributions to ability and effort. The significant correlations among the attributions to ability, task difficulty, effort, and luck/chance suggest interdependence. While ability was a reliable predictor of the student's final grade, attributions to task difficulty were also reliable predictors of the students' final grade. In addition, attributions to effort were statistically significant as well, but

were not deemed to be practically important due to the low percentage of variance explained. Peterson et al. (1985) also found significant correlations between the degree of frustration felt while working on assignments for the course and attributions to ability, task difficulty, and effort.

Another study (Kelley & Michela, 1980) reports that individuals tend to attribute success to themselves and failure to external sources. Algebra students believed that their ability was relatively stable over time and was a major cause of their performance in the class. This study indicates that students believe that their ability is a direct determinant of performance, and that feelings of frustration result when the student performs poorly in algebra or similar classes.

Cobb et al. (1992) report a follow-up assessment of a second-grade mathematics project whose development was guided by a constructivist theory of knowledge. These researchers compared the arithmetical learning, beliefs, and motivations of project and nonproject students at the end of third grade after both groups had received a year of traditional, textbook-based instruction in the same classrooms. The personal goals assessed by these scales were working hard (effort), making sense and collaborating (understand and collaborate), being superior to peers (ego), and not having to do any work (work avoidance). The results indicated that both project and nonproject students were motivated to work hard and to understand and collaborate. The only significant difference on this group of scales showed that project students were less motivated to be superior to their peers. Further results showed that both groups of students believed that success stems from working hard. This is consistent with their similar motivational orientations (effort).

At the end of the second grade, project students rejected the conjecture that conformity to the teacher's or peers' solution methods lead to success (conform). In contrast, nonproject students tended to agree with this conjecture. Project students also believed more strongly that the mathematics classroom is a place where success derives from attempts to understand and to explain one's thinking to others (understand and collaborate). At the end of the third grade, results indicated that project students now tend to agree with the conjecture, and nonproject students very firmly agree with it. The most surprising finding concerning the students' beliefs about reasons for success is that both groups agreed that attempting to understand and collaborate is important, albeit with differing degrees of firmness. In contrast to the differences in their beliefs about the reasons for success, the personal goals of the two groups of students were similar. Both groups generally achieved a sense of satisfaction when they worked hard (effort) and when they attempted to understand and collaborate.

Children often use ability and effort to explain successes (Frieze, 1980; Harari & Covington, 1981). Around age 9, a distinct conception of ability begins to emerge (Nicholls, 1978). With development, ability attributions become increasingly important in explaining successes, whereas effort declines in importance (Harari & Covington; Nicholls). These studies show that effective task strategies and attributions for task success have important effects on achievement outcomes. Successful problem solving is a prominent cue used to formulate ability attributions, and also is associated with perceptions of lower task difficulty (Weiner, 1974). Problem-solving facility should lead students to place less emphasis on effort and luck as causes of success. The negative influence of effort attributions on self-efficacy is consistent with developmental evidence, showing that ability attributions become increasingly important in explaining success, whereas effort as a causal factor declines in importance. Success attained with less perceived effort should promote self-efficacy more than when greater effort is required (Bandura, 1981). It is interesting that the largest direct attributional effect on changes in skill was found for effort.

Harari and Covington (1981) noted that children who stressed effort as a cause of success may have persisted longer on the posttest and thereby solved more problems. Greater persistence during cognitive skill learning promotes skillful performance. The findings from this study (Harari & Covington) are consistent with the idea that ability attributions exert stronger effects on performance expectancies than do effort attributions once children begin to form distinct conceptions of ability and effort. Research also demonstrates that attributional feedback like children's learning with attributions can have important effects. For example, teacher verbal feedback that attributes students' successes to their abilities (e.g., "you're good at this") leads to higher motivation, self-efficacy, and skill development than feedback linking successes to effort (e.g., "you've been working hard"). When children learn a task readily, ability feedback for their early successes promotes achievement outcomes better than ability feedback for later successes.

Teachers who judiciously deliver attributional feedback during classroom learning activities may help to develop students' skills and self-efficacy for applying them.

A study by Levin (1992) used a measure of students' willingness to participate in mathematics activities prior to high school as a third indicator of motivation for mathematics. Participants were in third, fifth, and eighth grades of urban public schools. Three motivational factors: confidence in one's ability to do mathematics, causal attributions related to mathematics performance, and willingness to attempt mathematics problems, were included in the study. The five component attribution categories used in the study were effort, ability, task, teacher, and luck. Results indicated sex differences were found in motivational measures. The expected pattern for success attributions (Gore & Roumagoux, 1983; Wolleat et al., 1980) suggests that males would attribute success primarily to effort. In addition, both males and females in the third and fifth grades attributed success primarily to effort, while male and female eighth-grade students attributed success primarily to ability. This pattern is consistent with the occurrence of a developmental shift in the conception of ability identified by Nicholls (1984). The expected pattern for failure attributions (Gore & Roumagoux; Wolleat et al.) suggests that females would attribute failure primarily to lack of ability and task difficulty more than would males. This study found that all students attributed failure to lack of effort.

Shores and Shannon (2007) examined the dimensions of self-regulation, cognitive strategy use, self-efficacy, intrinsic value, test anxiety, emotionality, worry, other, success, and failure to determine if they could be used to predict test score and math grade for fifth grade learners, each academic factor was examined in relation to self-regulated learning, motivation, mathematics anxiety, and attributions. It was noted that students receiving free-reduced lunch seemed to have higher test anxiety, allow more factors to affect test performance (i.e., emotionality, worry, other), and attribute failure in mathematics to lack of ability, lack of effort, back luck, poor rapport with teacher, or task difficulty more so than those students not receiving free-reduced lunch. Backward multiple regression indicated significant relationships between math grade and motivation, test anxiety, and attributions. More specifically, significant relationships were found between self-efficacy, worry, and failure. The model accounted for 33.2% of the amount of variance in math grade, and was significant in predicting math grade ($F = 21.891$, $p < 0.001$).

Conclusions/Recommendations

While attribution has been defined and identified by many researchers, some have begun to explore how it can be applied to the classroom for use by teachers and students. This review of literature discussed is the definition of attribution, the internal and external dimensions of attribution, and attribution in relation to mathematics. The majority of research discussed here indicates that an individual will attribute success and/or failure to either an internal or external cause that can be linked to ability and effort. Both ability and effort can be seen as causes related to success and/or failure.

The most important aspect to establish when examining attribution is to determine whether or not the success and/or failure are internal, external, or both. Some researchers (e.g., Stage et al., 1998) indicate that this may be different for males and females and whether or not they attribute the success/failure to a stable/controllable, stable/uncontrollable, unstable/controllable, or unstable/uncontrollable factor. Ability, effort, task difficulty, and luck are identified as the four categories to describe the above factors.

It is most important for teachers, specifically in mathematics, to be able to determine if students are attributing success and/or failure to ability, effort, task difficulty, and luck. This will assist teachers in determining if and when students attribute their success and/or failure to an internal or external cause, which, as mentioned earlier, is the first step in understanding why students behave the way they do. Research related to attribution and mathematics indicates that when students attribute success to external factors, they had lower achievement than when students attribute success to internal factors. In addition, success is most often linked to effort and ability, while failure is linked to task difficulty and luck.

The question is how to change attribution for a student from external to internal. Future research should focus on the development and study of intervention strategies involving beliefs related to ability and further development of a model involving mathematics learning, attributional styles, and specific attributions. The objective is to help mathematics students develop successful strategies for coping with or avoiding failure. Further examination of the ways in

which young children explain success and failure under a variety of school conditions could prove to be of significance. A new direction of research could examine when and at what age students develop or form distinct conceptions of ability and effort.

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How Preservice Teachers Interpret and Respond to Student Geometric Errors

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Recognizing and responding to students' thinking is essential in teaching mathematics, especially when students provide incorrect solutions. This study examined, through a teaching scenario task, elementary preservice teachers' interpretations of and responses to a student's work on a task involving reflective symmetry. Findings revealed that a majority of preservice teachers identified the student's errors from conceptual aspects of reflection rather than from procedural aspects. However, when they responded to the student's errors, preservice teachers tried to cope with them by invoking procedural knowledge. This study also revealed the three types of responses and two different forms of address by preservice teachers to student errors; these categories might provide insight into the difficulties arising in communication between students and teachers.

The idea of interpreting and responding to student thinking is highlighted as one of the central tasks of reform-minded mathematics teaching (e.g., National Council of Teachers of Mathematics [NCTM], 1991, 2000). Rather than transferring knowledge, teachers are increasingly called upon to create mathematics classroom environments where students reflect on their thinking and learn from their errors by explaining and justifying their ideas, asking their peers for more specific explanations, and helping other students work through their errors. The NCTM (2000) standards, for instance, emphasized that mathematical errors should not be seen as "dead ends" but rather as "potential avenues for student learning." They also recommended that teachers move beyond a superficial "right or wrong" analysis of tasks. In the same vein, Ball (1991) also emphasizes the importance of seeing errors as a window into student understanding and argues that teachers should endeavor to better understand the conceptual thinking behind student errors.

However, despite such reform efforts aiming to change the ways in which teachers handle and respond to student errors, the findings from the research have reported that the notion of student errors as "dead ends" rather than as "springboards for inquiry" into mathematical concepts still pervades in most mathematics classrooms (Ashlock, 1986; Fischbein, 1987; Greeno, Collins, & Resnick, 1996; Tsamir & Tirosh, 2005). In addition, studies that paid attention to the treatment of student errors in mathematics classrooms reported that teachers tended to avoid and hide student errors. Stevenson and Stigler (1992) and Schleppenbach, Flevares, Sims, and Perry (2007), for instance, investigate the use of errors in classroom discussion by comparing lessons of Chinese and U.S. teachers. They report that although U.S. and Chinese students made errors at similar frequencies, U.S. teachers tended to avoid and hide student errors, whereas Chinese teachers tended to redirect students to think about the original question in a different ways. Indeed, repeating the procedure until students recognize their errors is a well-known, typical strategy that U.S. teachers employ when dealing with their student errors in class (Borasi, 1994; Santagata, 2005; Stevenson & Stigler; Schleppenbach et al.).

In this study, we set out to investigate elementary preservice teachers' interpretation of and responses to student errors, and the relationship between their knowledge and approaches. Although abundant research has been carried out on teachers' treatment of student errors, there are still large gaps in this research (Ball, Lubienski, & Mewborn, 2001; RAND Mathematics Study Panel, 2003). For example, most of the research focuses on in-service teachers' handling and responses to student errors in classroom discourse (Ding, 2007; O'Connor, 2001; Fennema, Carpenter, Franke, Levi, Jacobs, & Empson, 1996; Fennema, Franke, Carpenter, & Carey, 1993; Lampert, 1992; Rittenhouse, 1998; Santagata, 2005; Schleppenbach et al., 2007; Stevenson & Stigler, 1992; Tsamir & Tirosh, 2005; Wang & Murphy, 2004; Wolcott, 1999). Preservice teachers' responses and their strategies to student errors is an area that has received limited attention in the research literature. If teachers are

called to use student errors as springboards for inquiry into mathematical concepts, it is important to explore preservice teachers' responses and their strategies to student errors and prepare them to make better use of student errors through teacher education programs. Furthermore, most studies have focused on numbers and operations, and have generally ignored other content strands such as geometry, measurement, and data analysis (Ball et al.).

In this study, we investigated how elementary preservice teachers recognize and respond to a student's errors and how their approaches relate to their mathematical knowledge. More specifically, we ask: How do preservice teachers interpret and respond to student errors on reflective symmetry?

Theoretical Background

In this section, we first provide a brief overview of research studies that have examined teachers' knowledge, approaches, and its relationship, and that provide our rationale for the design of this study. Then we discuss the analytical framework that was used to investigate preservice teachers' interpretation and responses to the student error(s) on reflective symmetry — conceptual versus procedural distinction.

Teacher Knowledge, Approaches, and Its Relationship

Since Shulman (1986) coined the notion of pedagogical content knowledge (PCK) for teaching, researchers have devoted considerable attention to what is needed in the classroom beyond "knowing the math" (e.g., Grossman, 1990; Shulman, 1987; Wilson, Shulman, & Richert, 1987). PCK is a form of practical knowledge that is used by teachers to guide their actions in highly contextualized classroom settings, and is both built with and builds upon teachers' subject matter knowledge as well as teachers' knowledge of pedagogy. In Shulman's (1986) view, PCK consists of "the ways of representing the subject which makes it comprehensible to others . . . [it] also includes an understanding of what makes the learning of specific topics easy or difficult . . . " (p. 9). PCK entails: (1) knowledge of how to structure and represent academic content for teaching to students; (2) knowledge of the common conceptions, misconceptions, and difficulties that students encounter when learning particular content; and (3) knowledge of the specific teaching strategies that can be used to address students' learning needs in particular classroom circumstances (Carpenter, Fennema, Peterson, & Carey, 1988; Rowan, Schilling, Ball, & Miller, 2001). Teachers' PCK closely relates to how they interpret and respond to student errors.

Abundant research has focused particularly on teachers' PCK in mathematics. While some researchers have examined teachers' PCK centered on teacher knowledge and strategies on the common mathematical concepts (e.g., Ball & Bass, 2003; Ma, 1999), other researchers have paid more attention to teachers' knowledge and approaches on misconceptions and errors that students encounter when learning particular content (e.g., Ding, 2007; Schleppenbach et al., 2007). For instance, Ball and Bass provided detailed knowledge for teaching mathematics by examining teachers' practice and described the use of teachers' PCK, such as how to represent quantities of 1/4 or 0.25 using diagrams, or to interpret and to evaluate students' multiple solution methods for a problem such as 35×25. Ma compared and contrasted U.S. teachers' mathematical knowledge and strategies to those of Chinese teachers around four different topics: whole number addition, whole number subtraction, fraction division, and perimeter and area. Articulating the knowledge needed for teaching mathematics as a "profound understanding of a fundamental mathematics" (PUFM), Ma reported that the Chinese teachers had a profound understanding of mathematics, while the U.S. participants had a procedurally developed understanding. She suggested four different ways that U.S. teachers could attain a PUFM such as (1) studying teaching materials intensively, (2) learning mathematics from colleagues, (3) learning mathematics from students, and (4) learning mathematics by doing it.

Different from the researchers described previously, other researchers have paid more attentions to teachers' knowledge and approaches on misconceptions and errors that students encounter when learning particular content (Ding, 2007; O'Connor, 2001; Santagata, 2005; Schleppenbach et al., 2007; Stevenson & Stigler, 1992; Tsamir & Tirosh, 2005; Wang & Murphy, 2004; Wolcott, 1999). For example, Ding investigated six elementary teachers' responses to student errors in teaching equivalent fractions. He reported that teachers responded differently to student errors although they had a similar level of understanding of equivalent fractions; only when teachers had knowledge bases with strong connections to mathematical foundations, they could flexibly activate and transfer their knowledge in responding to student errors in the teaching context. Using a cross-cultural lens for looking at teachers' responses to student

errors, Stevenson and Stigler showed how teachers in different cultures and countries vary in their approaches to student errors. They reported that Chinese teachers used errors to prompt student discussion of mathematical concepts and promote a classroom environment in which students do not feel ashamed to make mistakes. In contrast, U.S. teachers often tended to pose the original questions to other students rather than having students reason about and explain their errors.

Clearly, the wealth of research on teachers' PCK has implications for teaching and teacher education. However, there are still large gaps in this research (Ball et al., 2001; RAND Mathematics Study Panel, 2003). For example, research on ways of making full use of the educational potential of student errors has still remained unexplored. Only recently have researchers started to view errors as resources for promoting learning rather than simply as diagnostic tools (Schleppenbach et al., 2007). Preservice teachers' responses and their strategies to student errors is an area of PCK that has received limited attention in the research literature (Tsamir & Tirosh, 2005). If teachers are called to use student errors as potential avenues for student learning in current reform vision, it is important to explore preservice teachers' interpretation of, and responses to, student errors, and to provide them opportunities to make better use of student errors through teacher education programs.

In addition, although abundant research studies helped us understand the relationship between teachers' knowledge and their practice, the results are controversial. Some have reported the strong dependence between the two (Lehrer & Franke, 1992; Heaton, 1992; Parker & Heywood, 2000; Son, 2008; Spillane, 2000) with Lehrer and Franke reporting that when teachers were knowledgeable in a content area, they were able to modify activities included in reference materials and eliminate ones they judged to be tangential to the targeted conceptual understanding. Similarly, some researchers showed that the converse appears to be true; that is, a lack of content knowledge (CK) is related to incomplete and superficial level of PCK and limits a teacher's instruction (Carpenter et al., 1988; Heid, Blume, Zbiek, & Edwards, 1999; Putnam, Heaton, Prawat, & Remillard, 1992; Remillard, 1992; Spillane, 2000; Stein, Baxter, & Leinhardt, 1990).

In contrast, other studies showed no direct relationship between teacher knowledge and their practice (e.g., Begle, 1979; Leung & Park, 2002; Sánchez & Llinares, 2003; Stacey, Helme, Steinle, Baturo, Irwin, & Bana, 2001). Begle, for instance, sought to demonstrate a connection between teachers' knowledge and student achievement with quantitative studies and reported statistically insignificant correlation between two measures. Contradicting the widely accepted beliefs that the more teachers know about their subject matter, the more effective they will be as a teacher, these studies suggest that this belief needs drastic modification and in fact suggests that once a teacher reaches a certain level of understanding of the subject matter, then further understanding contributes nothing to student achievement.

Ding (2007), who investigated the relationship between teacher knowledge and their responses to student errors of equivalent fractions, reported that although teachers had a similar level of understanding of mathematics, they responded differently to student errors; only when teachers had knowledge bases with strong connections to mathematical foundations, they could flexibly activate and transfer their knowledge in responding to student errors in the teaching context. Indeed, whether there is a direct relationship between teacher knowledge and practice or not, teacher knowledge is still likely a significant factor in students' achievement, particularly in helping students overcome their errors. More important are the details of "how" and "when" these knowledge pieces are related to each other (Ball, Bass, & Hill, 2004).

Third and final weakness is that research studies on teacher knowledge have addressed a fairly narrow range of mathematics content areas (Ball et al., 2001; Mewborn, 2001). Mewborn articulated the topics that numerous researchers have addressed so far, such as the topics of place value, division, natural numbers (more specifically, fractions, with considerably less attention to decimals and ratios), and geometry (focusing almost exclusively on area and perimeter). Given the recent emphasis on mathematics as more than arithmetic, it seems necessary to know more about teachers' knowledge in domains other than number and operations. For example, a content area that seems to be crucial in mathematics education, but that has received little attention in the research literature is symmetry. The *Principles and Standards for School Mathematics* (NCTM, 2000) sets symmetry as one of the significant geometry concepts that provide insights into mathematics and into art and aesthetics. Continuing, detailed work on PCK is needed to chart,

identify, and describe the three forms of PCK listed previously as they relate to other school mathematics domains.

This article originated with our interest in learning more about PCK in the specific domain of geometry — symmetry — with preservice teachers. We set out to investigate elementary preservice teachers' interpretation of and responses to a student's errors of reflective symmetry and its relationship to their knowledge. We hypothesized that the preservice teachers with stronger CK would provide better responses to student errors, based on prior research findings showing that PCK correlates to CK (e.g., Carpenter et al., 1988).

Analytical Framework: Conceptual versus Procedural Knowledge

In analyzing preservice teachers' knowledge, interpretation, and approaches to student error(s), we were guided by studies such as Rittle-Johnson and Alibali (1999), which distinguish between the use of procedural and conceptual knowledge. Rittle-Johnson and Alibali defined *conceptual knowledge* as explicit or implicit understanding of the principles that govern a domain and of the interrelations between pieces of knowledge in a domain. They defined *procedural knowledge* as action sequences for solving problems. These two types of knowledge lie on a continuum and cannot always be separated: however, the two ends of the continuum represent two different types of knowledge (e.g., Halford, 1993; Hiebert & Lefevre, 1986; Gelman & Williams, 1997; Siegler & Crowley, 1994).

We use the terms action-based and property-based to denote a distinction often made between two forms of mathematical knowing previously described. Action-based methods involved procedural knowledge of reflective symmetry such as flipping and folding while property-based ones involved conceptual knowledge of reflective symmetry such as using equal distance or perpendicularity. More detailed examples of these two forms of knowledge regarding reflective symmetry will follow as we discuss the findings.

Research Study

We investigated preservice teachers' interpretation of and responses to student error(s) through a classroom scenario in which an imaginary student incorrectly reflected a flag across a slanted line of reflection. As part of a larger study, we also examined how preservice teachers' interpretation of and responses to the student errors are related their CK with respect to reflectional symmetry. Fifty-four preservice teachers participated in this study. They were majoring in elementary education or special education at a large midwestern university and had completed two mathematics courses focused on number sense and geometry, and one methods course.

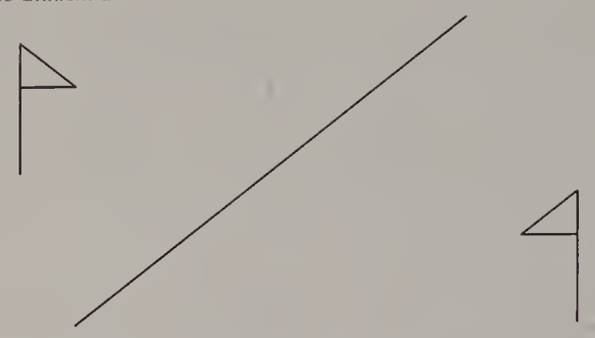

Figure 1. Emily's incorrect reflection.

Both tasks (CK and PCK) were developed based on Hoyles and Healy's (1997) set of paper-and-pencil items, Rowan et al.'s (2001) release items, and *the Everyday Mathematics Teacher's Lesson Guide* from first through sixth grade (Bell, Bretzlauf, Dillard, Hartfield, Isaacs, McBride, Pitvorec, & Saecker, 2002). The CK tasks were aimed at common misconceptions about reflection (as shown in Appendix B).

The PCK task involved interpreting and responding to one student's incorrect reflection, which was explored in Hoyles and Healy's (1997) study. Hoyles and Healy asked students to construct reflections in horizontal or vertical or the slanted line. In particular, they examined one student, Emily, who successfully reflected objects in horizontal or vertical mirror lines but failed to construct reflection when the mirror was slanted, as shown in Figure 1. We used this student's example of incorrect reflection to explore preservice teachers' PCK. The preservice teachers were first asked to identify Emily's error(s) and then to write down how they would respond to her (see Appendix A).

Understanding of Reflectional Symmetry

We mention briefly our findings with respect to the CK task, as they were helpful in providing an initial framework for analyzing the PCK task. On average, more than a quarter of the preservice teachers answered the first three questions incorrectly. In these questions, they were asked to identify the number of lines of symmetry in a parallelogram, to choose the description that most closely matched the properties of reflective symmetry, and to draw the reflection of a

Property-based	Action-based
"I drew lines from each vertex to the place on the opposite side where the distance would be the same from the mirror to the vertex. Then I drew in connecting lines and folded to check."	"I folded the page to show how it would look. I could if I wanted use a mirror."

Figure 2. An example of the property- and action-based solutions by preservice teachers.

Table 1
Percentage of Correct Responses Between Students with Property-Based Versus Action-Based Reasoning or Tasks

Reasoning/tasks	Task 1: Identify the number of lines of symmetry	Task 2: Choose a statement describing the properties of reflective symmetry	Task 3: Draw the reflection of a flag
Property-based	86%	91%	92%
Action-based	79%	42%	91%

flag (see Appendix B). In the fourth question, where preservice teachers were asked to explain their strategies, there were very few incorrect responses. In looking more closely at their explanations, we found that more than half the preservice teachers described reflection using action-based rather than property-based methods. As we described earlier, we use the terms action-based and property-based to denote a distinction often made between two forms of mathematical knowing — procedural knowledge and conceptual knowledge (Hiebert & Lefevre, 1986; Hiebert & Wearne, 1996; Rittle-Johnson & Alibali, 1999). Action-based methods involved procedural aspects of doing reflection such as flipping and folding while property-based ones involved conceptual knowledge of reflective symmetry such as using equal distance or perpendicularity (see Figure 2 for an example of each).

Table 1 shows percentage of correct responses to the first three tasks corresponding to students who described their reasoning from property-based vs. action-based. The preservice teachers who relied on action-based methods produced more frequently incorrect answers to the first two CK items than the preservice teachers using property-based methods whereas slightly higher percentage of students with property-based methods drew the correct reflection of a flag.

Recognizing Emily's Learning Difficulties

Although some view errors as part of the "messiness" of doing mathematics (e.g., Brown, 2000), student errors are often considered as catalysts for mathematics learning (Ashlock, 1986; Borasi, 1994; Lannin, Barker, & Townsend, 2007). In keeping with this latter way, teachers need to identify students' specific errors or learning difficulties and provide appropriate responses (e.g., Ashlock; Gable & Coben, 1990; Gable & Hendrickson, 1990).

Hoyles and Healy (1997) attributed Emily's learning difficulty to the fact that she had not yet connected her experiential meanings of reflective symmetry with any accepted mathematical definition. According to them, Emily operationalized a common set of invariant properties.[1] Thus, while Emily successfully reflected objects in horizontal or vertical mirror lines, she provided incorrect reflection to the slanted line.

Table 2
Preservice Teachers' Identification of Emily's Error

Type of identification	Subcategory	Number of responses	Total
Property-based	Diagonal line*	22*	31 (56%)
	Equal distance	8	
	Distance and angle	1	
Action-based	Flipping*	5*	10 (19%)
	Matching	1	
	Coordinating	1	
	Inverting	1	
	Rotating to slant line	2	
Misdiagnosed		13	13(24%)
Total		54	54

* Represent the most frequently referred category.

With the slanted mirror line, she constructed the image by prolonging the object through the mirror line and flipping — obtaining a rotation rather than a reflection (see Figure 1).

Conceptual versus Procedural Knowledge

In analyzing the responses of the participants, we identified three categories, which we describe and illustrate later. To establish these categories, we were guided by studies, such as Rittle-Johnson and Alibali (1999), which distinguish between the use of procedural and conceptual knowledge. Thus, our first interpretation was to classify different ways of identifying Emily's learning difficulties using a conceptual approach — in this case, focusing on the invariant properties of symmetry, in which the following hold: (1) the reflected images is the same size and shape as the original, (2) it is the same distance away from the mirror, and (3) it is "opposite" or "reversed." We call this type of identification of Emily's error as *property-based*. One typical response was as follows:

- Emily was not using the mirror to reflect the image. She also does not understand that with symmetry. Each point of the design or picture has to be the same distance away the line of reflection, and also has to be the same angle from the line as the original figure.

In contrast, a procedural approach included the following types of responses:

- She doesn't realize that reflection doesn't just involve flipping the image. It involves reflecting the image over the diagonal line, which is probably different from work she's done before with just a vertical line.
- She did not flip the object.

The procedural approaches always included mention of Emily not performing the correct action of folding or using the mirror. This type of identification of Emily's error is called *action-based*. In addition to these two categories, a third one involved responses that misdiagnosed Emily's error — the following are examples:

- The only thing that I can see she doing wrong is that her reflection is slightly off but I think I am wrong. I figured it but I had a really hard time going from wrong reflection to right reflection.
- She doesn't understand what a reflection is and that you rotate it."[2]

Table 2 provides an overview of the pattern of responses given.

Among the preservice teachers who recognized Emily's learning difficulties from conceptual aspects of reflective symmetry, 22 of them (out of 31) stated that Emily had difficulties with the line of reflection being "slanted."

- "She is unable to see the reflection correctly because the line of reflection is on a tilt."
- "She is reflecting the shape over a straight line + not over a diagonal one."

Indeed, it is a well-known difficulty that students have in performing reflections: they tend to be biased

Table 3
Preservice Teachers' Pedagogical Strategies

Type of strategies	Subcategory	Number of responses	Total
Property-based	Diagonal line*	11*	25 (46%)
	Equal distance	6	
	Distance and angle	8	
Action-based	Flipping	1	22 (41%)
	Folding*	11*	
	Matching	1	
	Graph paper	2	
	Showing	1	
	Mirror	4	
	Rotating to slant line	2	
Misdiagnosed		7	7 (13%)
Total		54	54

* Represent the most frequently referred category.

toward a vertical line of reflection. Our fictitious Emily made a reflection as if the line of reflection was vertical, and then compensated by gliding the image down a little.

Responding to Emily's Work

We performed the same analysis on the responses the preservice teachers gave to the question that asked them to describe how they would respond to Emily. In conjunction with the studies on students' mathematical knowledge development, researchers have revealed that instruction that includes a conceptual rationale for procedures leads to better understanding than procedure-only instruction (Fuson & Briars, 1990; Hiebert & Wearne, 1996). We first classified whether preservice teachers provided concept-oriented responses to Emily, namely, responses that focused on the invariant properties of reflection, or procedural-oriented responses related to the actions of creating a reflected image. Table 3 shows the distribution of response in terms of concept-oriented versus procedural-oriented.

We were intrigued to find out how the preservice teachers who recognized Emily's error in terms of properties of reflections would respond to Emily. A comparison of Tables 2 and 3 shows that the frequency of focusing on the properties of reflection decreased from identifying the learning difficulties and responding to it, while the frequency of focusing on active creation of reflection increased. If our categorization of conceptual versus procedural knowledge holds, then even though preservice teachers identified Emily's errors in terms of conceptual knowledge, they tried to cope with it by resorting to procedural knowledge such as folding and flipping.

Digging Deeper: Beyond the Conceptual versus Procedural Distinction

Although the procedural versus conceptual distinction is well grounded in the research, conducted mostly on whole number operations, we came across several controversial issues. First of all, the empirical evidence on the effect of conceptual versus procedural instruction is mixed. Indeed, in some domains, such as counting, students are likely to better understand the underlying concepts after experience using the correct procedure (Briars & Siegler, 1984; Fuson, 1988; Wynn, 1990). Second, while we categorized folding and flipping as procedural, both strike us as being quite different from, say, the invert-and-multiply procedure for fraction division. Folding and flipping both provide concrete, embodied actions that are meaningful to students, whereas the invert-and-multiply procedure clearly does not. In other words, flipping and

folding may well become procedures that enable students to construct reflected images, but those actions also provide conceptual support. We thus wondered whether the procedural/conceptual distinction was useful in our context, and whether another way of categorizing the data would provide more insight into the effectiveness of teacher responses.

As the conceptual versus procedural distinction proved to be challenging to make in the case of reflectional symmetry and questionably appropriate according to the previously mentioned research, we decided to probe the range of responses we received using a different approach. We were initially surprised that only 11 of 54 teachers tailored their response to Emily in a way that directly addresses her difficulty with the specific task (namely, the slanted line of reflection). Some of these responses were conceptually oriented, while others were procedurally oriented. Moreover, the responses provided by the preservice teachers who were not able to identify Emily's error (32 in total) showed many similarities with the responses of the 11 preservice teachers who were able to identify Emily's difficulty, but who chose to not address it directly in their responses (indicating that preservice teachers may not respond to particular problems that students have but may instead offer more general responses that might address a number of different difficulties).

Closer inspection of the nondirected responses (43 in total) provides some insights into the difficulties students and teachers have in communicating. We distinguished three categories of responses that we believe reflect a number of interesting psychological, pedagogical, and mathematical aspects of teachers' practices. Instead of coming from the research literature, we devised these categories by looking for common patterns among the responses.

The most prominent type of response (which again, did not directly address Emily's error) involved the *generalization* of properties. In these responses, the preservice teachers responded to Emily by invoking the general properties of reflection; examples include:

- "I would show her how to match up sides with respect to the line."
- "I would tell her to use a ruler."
- "I would talk about perpendicular lines."

Each of the responses in this category involves "showing"/"telling"/"talking about" properties of reflection (equidistance to the line, perpendicularity, etc.) that we argue are at a more general level than that of the actual error. They are responses that would apply equally well to a situation in which a student has produced either of the reflections shown in Figure 3.

Supposing Emily did understand or follow the instructions given by these responses, she may well be able to create the correct reflection. However, doing so would not necessarily help Emily understand the invariant features of reflection using vertical and diagonal line of reflection.

The second most prominent category involved a *return to the basics*. These responses included some that were already discussed in the previous section, where the preservice teachers offered Emily mirrors or folding paper. They also include responses such as:

- "Give her an easier drawing."
- "I would try to show Emily a pole with a flag."
- "I would have Emily practice with a straight line before using a line that is on an angle."
- "I would begin by showing her real-life examples."

We find this category of responses interesting in its similarity to a didactic move we have experienced often ourselves (both as learners and teachers), which involves a return to the building blocks, to the first principles, to the basics. In fact, Emily may not need to go so far back in order to address her error and doing so may either make her forget her original problem or introduce still more problems; it may well be the extensive use of "basic" vertical lines that led Emily to create the wrong reflected image in the first place. While the previous category shows a tendency to run ahead of Emily's needs, this category concerns the tendency to run behind her needs.

The third and final category of responses we observed involved *a Plato-and-the-slave-boy approach* in which the preservice teachers appealed to the notion

Figure 3. Incorrect reflections that are covered by the *generalization* responses.

that Emily actually did know how to do the reflection correctly, but had simply forgotten. This third category of response thus involved reminding Emily of the properties of reflection, or asking her to remember those properties. Examples include:

- "I would remind her that she should remember that every point on this shape needs to have a line drawn from it and intersect the mirror at a 90 degree angle. Then I would remind her to measure the distance from each point."
- "I would tell Emily that she is on the right track for reflecting images. But that she needs to remember to not only flip the images but also make it so that it is a mirror-image along the line she reflects over."
- "I would remind her to measure the distance from each point on the flag to the mirror [. . .]."
- "I would review what a line of symmetry means."

In these responses, the preservice teachers assume that Emily had indeed already learned about properties of reflection. This was not implied by the problem, except perhaps to say that Emily was in sixth grade. The examples shown previously could also be classified as *generalizations* but we distinguish them here because of their unique didactic flavor. Recalling memory strikes us as more useful in situations where students are faced with fact-retrieving or procedural hurdles (including questions about naming conventions — what does FOIL stand for again? What is the name of this line between the two reflected images? — but perhaps also including issues related to what Hewitt (2001) calls " 'arbitrary' rather than 'necessary' knowledge"). We are pursuing the idea here that asking the student to "remember" may actually (inadvertently) communicate to the student that the situation calls for memory rather than understanding.

In addition to the three types of responses identified previously, we were intrigued by the form of address adopted by the preservice teachers toward Emily. While most responses involved using Emily's name or referring to "her" and "she," two responses involved direct imperatives in which Emily was only an implied presence (for example: "all points on the flag bottom of 'flagpole' of both figures must be an equal distance from the line of reflection," "do not simply reflect over the line in a straight path"). In the other 43 responses (three responses were blank), we found that the forms of address were of one of the following two forms:

- "Show" and "Tell": The response delivers verbal or nonverbal information to Emily to hear or see — explaining a procedure, telling a fact, showing an image, making a fold, etc. The responses usually used the very words "show" or "tell" but also used "explain," "talk to," and "look at."
- "Give" or "Ask": Here, the response involves Emily delivering verbal or nonverbal information — to do something with a manipulative, image or question that is given to her.

Each of these categories has already been illustrated in the responses provided previously. The "show" and "tell" responses far outnumbered (32 out of 43) the "give" or "ask" ones. This seems consistent with Davis's (1996) observation that teachers do not often listen to their students, preferring instead of deliver information. As preservice teachers may not know what it means to "listen" to students and how such forms of responses differ from their preferred forms of address, we propose that reflecting on these responses with preservice teachers may be very productive — as would considering further the instances for which "telling" and "showing" might be most appropriate.

Discussion and Implications

> I am really worried about teaching something to kids I may not know. Like long division — I can *do* it — but I don't know if I could really *teach* it because I don't know if I really *know* it or know how to *word* it (Ball, 1990, p. 104).

Dewey (1990) claimed that knowledge for teaching is different from knowledge for "doing" in a discipline. Merely "knowing" more mathematics does not ensure that one can teach it in ways that enable students to develop the mathematical power and deep conceptual understanding envisioned in current reform documents (e.g., NCTM, 2000). Work on PCK has also argued that good practice involves more than just strong CK; teachers should have not only knowledge of mathematics but also knowledge for teaching mathematics. Upholding this view, we started our study with a hypothesis about the positive relationship between CK and pedagogical strategy, such as the preservice teachers with stronger CK would provide better responses to student errors.

We saw some relationship between preservice teachers' CK and their ability to identify Emily's incorrect answers. However, we noticed that things became more blurred when it came to providing Emily with a good response. For example, our exploratory

analysis showed that a large portion of preservice teachers had a tendency to rely on procedural aspects when they gave instruction even though they recognized the students' learning difficulties in terms of conceptual aspects. We also saw that while CK was related to conceptual approach, which did not always provide the best responses either. Some preservice teachers who provided their instruction from conceptual aspects did not directly address Emily's difficulty with this problem; some properties they mentioned might not help Emily be aware of what is going on and where she would go.

Why does this happen? Although these findings can be supported by several previous studies that found no direct relationship between teachers' CK and PCK (e.g., Begle, 1979; Leung & Park, 2002; Sánchez & Llinares, 2003; Stacey et al., 2001), and contribute to narrow the gaps of the current research on PCK by providing more detail information on "how" and "when" such knowledge pieces are related/or not related to each other, we propose the following two reasons that we think could explain this complex relationship between CK and pedagogical approaches: (1) preservice teachers' insufficiently developed knowledge of pedagogical strategies and (2) the different nature of procedural knowledge in geometry (in particular, reflective symmetry).

First, we think that preservice teachers' insufficiently developed PCK results in this complex relationship. There are a variety of knowledge and strategies that teachers need to know in order to respond to student errors adequately. However, preservice teachers in this study did not seem to fully develop such knowledge and strategies — in particular, teaching strategies that deal with student errors and misconceptions, and accordingly, their incomplete and superficial levels of knowledge limited their instruction to Emily. Indeed, a number of studies reported that preservice teachers (and novice teachers) tended to struggle, and sometimes failed to come up with powerful means of representing subject areas to students, although they recognized student misconceptions and errors correctly; therefore, their efforts that help students overcome their errors were often time-consuming and inefficient (Brown & Borko, 1992; Carpenter et al., 1988; Cochran, DeRuiter, & King, 1993; Feiman-Nemser & Parker, 1990). Eisenhart, Borko, Underhill, Brown, Jones, and Agard (1993) also showed that although preservice teachers (and novice teachers) had a strong knowledge of mathematics, they had much more difficulty with articulating a conceptually oriented approach than they could articulate their ideas of a procedurally oriented approach although they have strong knowledge of mathematics. Likewise, preservice teachers' inability to respond to Emily on a conceptual level, despite having identified her conception of reflection as the area of difficulty, may suggest insufficiently developed PCK.

Second, we think that the different nature of procedural knowledge in reflective symmetry would be another reason for procedurally oriented instruction by the preservice teachers. We used the procedural/conceptual distinction to explore the relationship between CK and ability to identify and respond to Emily's incorrect answer. However, this framework might not fully capture an instruction that would be useful in our context. As we discussed earlier, we categorized folding and flipping as procedural aspects of reflective symmetry. Yet, such procedural knowledge is quite different from that of number and operations (e.g., the invert-and-multiply procedure). The terms "procedural knowledge" does not seem appropriate to describe the understandings that students have and the approaches that teachers can use (Rittle-Johnson & Siegler, 1998; Star, 2005). For example, folding and flipping both provide concrete, embodied actions that are meaningful to students, whereas the invert-and-multiply procedure clearly does not. The procedural knowledge of reflective symmetry may well become procedures that enable students to construct reflected images, which provides conceptual support. Brown, Moran, and Williams (1982) argued that procedures should not be assumed to be rote but rather as objects with several different sources of meaning. For this reason, the preservice teachers in this study might use procedural aspects of reflection in responding to Emily although they recognize her errors from the conceptual aspects. This calls for reevaluation on the use of this framework — the conceptual versus procedural distinction — in other areas of content in mathematics as well.

The preservice teachers were being asked to imagine a student they knew little about, and the responses they provided may not fully coincide with the types of responses they would give in a live situation. Nonetheless, we think that there are certain aspects of their responses that indicate more general beliefs and tendencies that play an important role —

alongside CK and the ability to recognize student errors — in developing response strategies for students.

For example, analyses of the nondirected responses to Emily's incorrect answers helped us identify the three types of teaching strategies to Emily — *the generalization of properties, a return to the basics*, and *a Plato-and-the-slave-boy* approach — which we believe cause the difficulties students and teachers have in communicating. These three categories provide interesting trends that appear when preservice teachers attempt to give instruction to students who make errors, and calls for special attentions to teacher educators and teacher education programs.

First, the most prominent category — the generalization of properties by showing and telling — indicates that despite current reform efforts aiming to change teaching practice, the notion of teaching as telling (showing, explaining) rather than facilitating (listening, interpreting) still pervades among the preservice teachers in this study. Cobb (1988) reported that when teachers do not seek to understand or do not seek to analyze their students' thinking, they tend to dismiss it by imposing their own formalized constructions onto the students. A case in point is preservice teachers in the first category. Indeed, this type of responses would apply equally well to a situation in which a student has produced any incorrect reflections. More consideration on how to help preservice teachers change their view of teaching and develop their approaches in ways that allow them to interpret student thinking in the process of dealing with student misconceptions is needed in teacher education programs and research studies.

In addition, none of these categories described earlier responded to particular problems that Emily has. Preservice teachers with the first and third categories — *the generalization of properties* and *a Plato-and-the-slave-boy approach* — show a tendency to run ahead of Emily's needs, whereas the second category — *a return to the basics* — concerns the tendency to run behind her needs. As Eisenhart et al. (1993) pointed out, these approaches may be time-consuming and inefficient or may offer more general responses that might address a number of different difficulties than repeating the procedure until students recognize their errors.

Teachers, like their students, are learners who need to be taught in innovative, flexible ways. Indeed, it is difficult for teachers to use student errors as potential avenues for student learning suggested by NCTM (1991, 2000) without similar learning experience in their teacher preparation programs or professional development programs. In order for teachers to use student errors as a teaching tool, they should have opportunities to learn mathematics in ways that reflect on their thinking and learning from their errors by explaining and justifying their ideas, asking their peers for more specific explanations, and helping other students work through their errors in teacher education programs, as students will do in their future classrooms. In addition, preservice teachers should have an opportunity in teacher education programs to examine student errors, to discuss possible strategies they could use, and to modify their strategies based on the discussion to respond to student errors appropriately.

This study has implications for teacher educators, teacher education programs, and researchers. First, our study joins others (e.g., Ball & Bass, 2003; Ma, 1999) in highlighting the importance for teacher educators to consider how to help intending teachers learn to interpret and respond to student errors effectively in their mathematics teaching. In particular, by identifying different types of responses and forms of address, teacher educators may be in a better position to raise preservice teachers' awareness of the implications of their interactions with students. It can also help them develop prompts and facilitate discussions of such tasks that can challenge and expand the preservice teachers' initial understandings and imagined practice.

In addition, this study suggests that teacher educators might increase attention to and emphasis on geometry. Our study revealed that more than a quarter of the preservice teachers consistently showed a lack of CK to symmetry and more than half of the preservice teachers referred to procedurally focused approach to Emily. Porter (1989) argues that one of the factors influencing students' poor performance on geometry from teachers' lack of attention to this topic. Likewise, teacher education program's lack of emphasis on geometry might cause preservice teachers' lack of attentions and their lack of abilities to teach geometry.

Lastly, this study calls for mathematics education research that continues to investigate preservice and also in-service teachers' interpretation and responses to students' errors or learning difficulties. In particular, this study highlights the need to focus on how

to help preservice teachers interpret and respond to students' errors appropriately. If student errors are considered as catalysts for mathematics learning and teachers need to identify students' specific errors or learning difficulties and to provide appropriate responses, it is necessary to study teachers' interpretation and response to students' errors, and to use the information gleaned to inform teacher education programs. In addition, it calls for more studies that examine other possible students' specific errors or learning difficulties and appropriate responses in this and in other mathematical topics.

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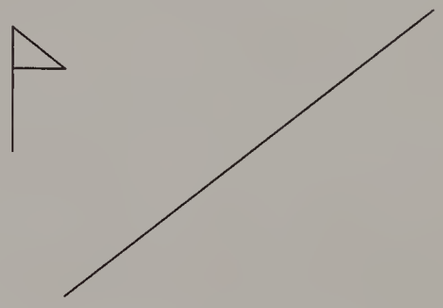
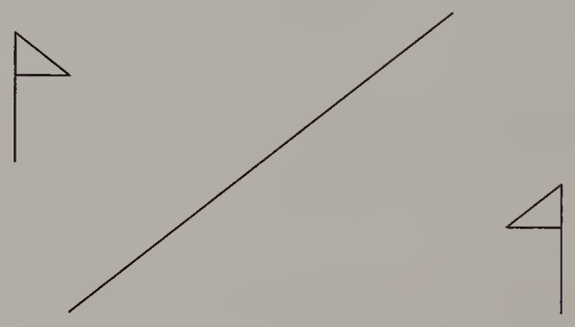
Appendix A

Pedagogical Strategy Assessment Task

Imagine you are a 6th grade teacher. You ask your students to solve the problem below.



One of your students, Emily, solved this problem below.

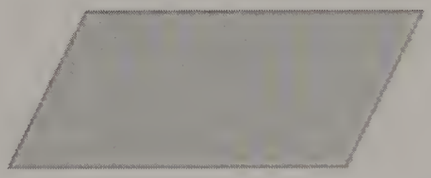


1. What are Emily's errors in doing reflective symmetry?
2. How would you respond to Emily? Describe and explain your strategies as much detail as possible.

Appendix B

Content Knowledge Assessment Task

1. Mr. Allen was working with his class on reflective symmetry. He told his class that if we drew a vertical line down the middle, the left side of each would be a "mirror image" of the right side. We call this line "line of reflection or symmetry." Then, Mr. Allen asked his students to find the lines of symmetry. How many lines of symmetry can you find in the shape below? (Mark one answer.)



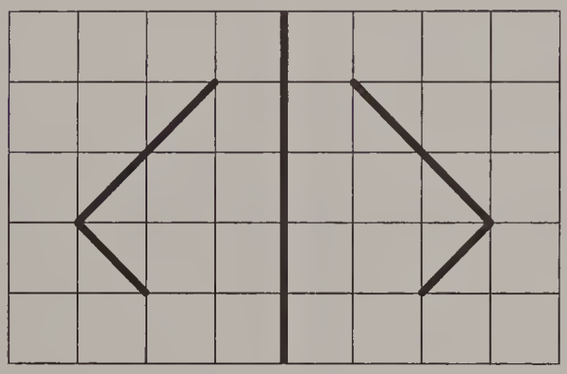
1) 0
2) 1
3) 2
4) 3
5) 4

Authors' Notes

[1] Which the reflected images is the same size and shape as the original, it is the same distance away from the mirror, and is "opposite" or "reversed."

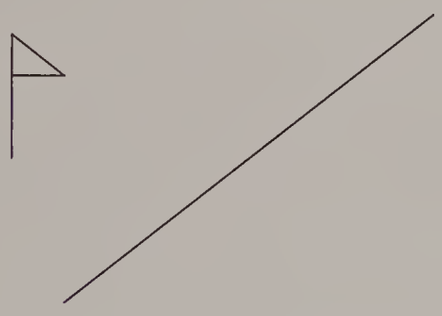
[2] The preservice teachers often confused reflection with rotation. When they were asked to identify Emily's errors, some spoke in terms of rotation, like "she didn't rotate it to the correct angle relative to the angle the line reflection has on." When they responded to Emily's errors, such confusion also appeared like "I would tell her to take the original shape and rotate it. Perhaps having a tangible object might make this easier for her to understand."

2. Mr. Allen asked his students to draw the reflective symmetry by using a mirror. Many students drew the figure below. One of his students asked why the figures are symmetric. He asked the other students to explain. Which of the following statements comes closest to explaining the reason for the reflective symmetry? (Mark one answer.)



1) The two drawings are the same size but different shape
2) The two drawings are facing in the same direction
3) Each vertex is the same distance away from the mirror
4) When the original drawing is rotated, the two drawings match

3. How would you solve the problem? Show your work below.



4. Explain how you solved the problem.

Sheryl L. Stump
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Reflective Tutoring: Insights into Preservice Teacher Learning

An undergraduate seminar was designed to help preservice teachers focus on students' learning. Preservice teachers planned and conducted weekly tutoring sessions with fourth graders and discussed their experiences in weekly discussions. The author investigated what preservice teachers learned about teaching mathematics from their focus on students' learning of mathematics. The author examined the tasks that preservice teachers posed to children, the questions they asked of children, and the reflections they wrote about their experiences. The article describes what the preservice teachers learned from their experiences and provides insights into their knowledge and skills for developing children's mathematical power.

While the notions of good mathematics teaching advocated by reformers have shifted from primarily teacher-centered practices of direct instruction to the inclusion of more student-centered experiences of mathematical inquiry and discourse (National Council of Teachers of Mathematics [NCTM], 2007), evidence suggests that the actual practices of many classroom teachers have *not* shifted (Wilson, Cooney, & Stinson, 2005). Thus, based on their extensive experiences as students in mathematics classrooms, many preservice teachers come to their teacher education programs with teacher-centered views of mathematics teaching.

The *Principles and Standards for School Mathematics* (NCTM, 2000) promotes a view of mathematics teaching that focuses on students' *learning*. The Teaching Principles states, "Effective mathematics teaching requires understanding what students know and need to learn and then challenging and supporting them to learn it well" (p. 17).

In an effort to help preservice teachers focus on students' learning, the author designed a semester-long seminar, "Reflective Tutoring: Developing Children's Mathematical Power." In addition to providing opportunities for children to learn mathematics and preservice teachers to develop their knowledge and skills for teaching mathematics, the seminar provided an opportunity for the author to address the following research questions: What do preservice teachers learn about *teaching* mathematics from focusing on students' *learning* of mathematics? How is the preservice teachers' learning about the teaching of mathematics reflected in the tasks they pose to elementary students, the questions they ask of elementary students, and the reflections they write about their experiences? This article will describe the seminar and articulate some insights into the answers to these questions.

A Seminar for Preservice Teachers

This seminar was different from the "methods" classes that the author had usually taught. Instead of beginning with standards, theories of learning, curriculum materials, instructional tools, and lesson plans, and then applying those ideas in limited field experiences, the seminar began with *students*. It was hoped that this experience would provide preservice teachers with an opportunity to examine the impact of their actions on student learning.

The seminar participants were 11 preservice teachers — 5 majoring in Elementary Education, 4 majoring in Secondary Mathematics Education, 1 double majoring in Elementary Education and Secondary Mathematics Education, and 1 majoring in Art. Their "students" were 11 fourth graders selected for an after-school tutoring program because they had failed the mathematics portion of the third-grade state test.

The seminar met twice a week for a semester — one session each week was devoted to tutoring and the other was devoted to discussion. The tutoring sessions provided opportunities for preservice teachers to focus on the development of a single student's mathematical understanding over an extended period of time, and the discussion sessions provided opportunities for them to share their ideas with each other and report on what went well and what did not. The alternating

experiences of tutoring and discussion provided opportunities for preservice teachers to engage in an ongoing cycle of assessment, planning, instruction, and reflection.

Diagnostic Instruction

The seminar was designed around the notion of *diagnostic instruction*, defined by Ashlock (2006) as a continuous cycle of seeking information about students' understanding of mathematical concepts and skills, and planning instruction in response to that information. The preservice teachers practiced diagnostic instruction as they met with their students in the weekly tutoring sessions and developed subsequent tutoring plans. The mathematical focus of the tutoring sessions was number sense and computation. The preservice teachers first administered a pretest aligned with state standards for mathematics. Beyond that, they were responsible for conducting a diagnostic interview and for developing their own weekly tutoring plans and materials. Each preservice teacher received an older edition of *Elementary and Middle School Mathematics: Teaching Developmentally* (Van de Walle, 2004) to use as a resource during the semester. The general format for the preservice teachers' tutoring plans and report appears in Figure 1.

The instructor also practiced diagnostic instruction in the weekly discussion sessions where the preservice teachers reported on their tutoring experiences, discussed the challenges they were facing, and turned in written plans and reports. The preservice teachers' oral and written comments helped the instructor select relevant ideas about teaching and learning mathematics to introduce in subsequent discussions. Topics such as conceptual and procedural knowledge, worthwhile mathematical tasks, questioning and listening, invented and standard algorithms, and helping children master basic facts arose from the preservice teachers' focus on actual students.

Developing Children's Mathematical Power

The notion of tutoring to develop children's mathematical power was challenging to the preservice teachers. According to their written accounts, their previous experiences with tutoring mathematics were focused on "explaining." In contrast, the seminar challenged preservice teachers to plan tutoring sessions that would help children develop their understanding of mathematical concepts, language, symbols, and procedures and engage children in problem solving, communication, reasoning, connections, and representation.

Tutoring Plans and Report

Tutoring Plans

1. **Goals/Objectives.** What do you hope to accomplish during this tutoring session?
2. **Tasks & Problems.** What tasks and problems will you present to the student? For each task or problem, write a series of questions designed to probe the student's mathematical thinking. In general, try to involve the student in discovering new concepts and connecting those concepts to mathematical language, mathematical symbols, and mathematical procedures.

Tutoring Report

1. **The Tutoring Session as Conducted.** Write a complete account of what actually happened.
2. **Analysis of the Session.**
   a. What did you learn about the student's understanding of mathematical concepts, mathematical language, and mathematical procedures? What does the student actually understand? What does the student not yet understand?
   b. How did the student demonstrate problem solving, communication, reasoning, connections, and representation?
   c. If you conducted this session again, how would you modify your tasks, problems, and questions?
3. **Prescription.** Describe what you think might be an appropriate focus for the next tutoring session.
4. **Self-Reflection.** What did you learn about learning and/or teaching mathematics as a result of this tutoring session?

Figure 1. General format for weekly tutoring plans and report.

The discussions about how to help children develop mathematical power focused on classroom *discourse*, and the tutoring sessions provided opportunities for preservice teachers to practice some recommended aspects of its orchestration (NCTM, 2007). In particular, they were encouraged to pose tasks and questions that would elicit, engage, and challenge children's thinking, and then to listen carefully to children's ideas. They were also encouraged to ask children to justify their ideas orally and in writing, and to promote the use of multiple representations. And although they found it particularly challenging, they were encouraged to decide when to provide information and when to let children struggle with difficulties.

Insights into Preservice Teachers' Knowledge and Skills

Insights into preservice teachers' knowledge and skills for teaching mathematics were gained by examining their written work throughout the seminar. In particular, evidence of their understanding and commitment to developing children's mathematical power could be seen in the mathematical tasks and questions that preservice teachers posed to students.

Mathematical Tasks

The preservice teachers soon realized the importance of finding or developing tasks that would challenge and interest the fourth graders. It seemed that few preservice teachers actually used the Van de Walle (2004) resource to plan their tutoring sessions, but the instructor was committed to letting the preservice teachers make their own decisions. The following types of tasks gradually appeared in many of their tutoring plans: solving word problems to introduce computation with whole numbers and fractions; using base-ten blocks or fraction circles to develop number sense and solve computation problems; writing word problems to contextualize computation with whole numbers and fractions; analyzing relationships between addition and subtraction, multiplication and division; developing strategies for basic facts; and playing games to practice basic facts.

Cognitive demand. An overview of the preservice teachers' attempts to develop children's mathematical power can be seen in Table 1, which shows the tasks from their tutoring plans sorted into the levels of cognitive demand described by Smith and Stein (1998). In this framework, it appears that a portion of the tasks designed by preservice teachers demanded somewhat high levels of children's thinking. Many of the tasks, though, were at the lowest level of cognitive demand and very few were at the highest level.

Mathematical Questions

Analysis of the questions in their tutoring plans and written reflections revealed insights into preservice teachers' interactions with children.

Types of questions. Some of the questions in their plans addressed *conceptual* aspects of mathematics, requiring the use of problem solving, communication, reasoning, connections, or representation to engage in the concepts. Other questions addressed *procedural* aspects of mathematics that focused on what and how, or leading questions that forced a particular way of thinking about a problem. The descriptions of these types of questions, along with examples, are shown in Figure 2.

The percent of questions of each type appearing in preservice teachers' tutoring plans over the entire semester appear in Table 2. It is encouraging to see that all of the preservice teachers included conceptual questions, in addition to the more prevalent procedural questions, in their tutoring plans. This suggests that preservice teachers had the ability to pose questions to probe children's mathematical thinking. The actual questioning techniques of preservice teachers, though, were revealed in another way.

Audiotape transcripts. Early in the semester, the preservice teachers taped one of their tutoring sessions and made a transcript of the audiotape. The purpose of this exercise was for them to observe their own patterns of discourse and then describe their observations. It proved to be an important learning experience lesson for the preservice teachers. Here is what some of them said:

> *Cecily*: One of the most important things I learned was that I often need to give Kaylene more time to work through a problem before I prompt her with a question. I realized that I spent most of the lesson talking and that I rarely had her explain her thinking process to me.

> *Frank*: The number one thing I learned about Elliot is really how little he talks during our time together. He does answer all the questions I ask him, though, which I guess is the important part. As for mathematics, I noticed that his language and descriptions need a lot of work. As for myself, I have realized an important problem: I talk too much. I guess this is me thinking that

Table 1
Levels of Mathematical Tasks in Preservice Teachers' Tutoring Plans

Preservice teacher	Percent of tasks at each level of cognitive demand			
	Memorization	Procedures without connections	Procedures with connections	Doing mathematics
Elementary Education majors				
Alice (n = 29)	24	34	38	3
Bethany (n = 57)	12	37	47	4
Cecily (n = 42)	17	10	74	0
Diana (n = 35)	17	34	46	3
Erin (n = 57)	26	16	46	12
Mathematics Education majors				
Frank (n = 41)	20	46	34	0
Gerald (n = 27)	7	48	44	0
Hanna (n = 37)	27	30	43	0
Irene (n = 45)	33	18	47	2
Double major				
Jillian (n = 37)	30	22	43	5
Art major				
Katy (n = 24)	8	54	33	4

Note: The variable n represents the number of tasks in each teacher's tutoring plans.

> I need to explain everything or ask silly questions. . . . All the questions I ask seem to get pretty repetitive.
>
> *Irene*: I now realize that Jason does not answer many of the questions that would really help me understand his mathematical understanding. I do not know if I need to reword my questions.

Written accounts. Later in the semester, as another exercise, the preservice teachers wrote down every question they asked during one of the tutoring sessions. (They did not have to write the children's responses.) Then they wrote a reflection critiquing how well their questions probed and promoted the children's mathematical thinking. Table 3 shows the percent of questions of each type appearing in preservice teachers' written accounts of the tutoring session. Here the questions were more procedural. It was especially disappointing to see the number of leading questions appearing in many of their written accounts.

Even though preservice teachers' questions revealed limitations in their abilities to engage children's mathematical thinking, their written comments revealed that they were aware of the importance of the questions they asked and the impact on children's learning.

> *Bethany*: I think I asked Leah some good, probing questions during the tutoring session. She is usually quiet, so I have to get her to open up and start talking a lot. I try to ask her questions about how she is solving a problem, instead of telling her straightforward that she solved it incorrectly.

Conceptual Questions	Procedural Questions
Problem Solving: The question extends beyond the use of procedures or addresses the use of strategies. "What patterns do you see in the rows and columns?" "Is there another way you could have solved this problem?" **Communication**: The question asks the student to describe mathematical ideas or explain mathematical terms. " What can you tell me about multiplication?" "What does $\frac{3}{4}$ mean?" "What is the purpose of a decimal point?" **Reasoning**: The question asks the student to provide a reason for why they made a particular decision or a justification for why something is true. "Why did you choose to add?" "How do you know that number is the larger number?" "How can we be sure that answer is correct?" **Connections**: The question asks the student to describe connections between mathematical ideas or representations. "How are addition and subtraction related?" "How does this problem compare to the ones with the base-ten blocks?" **Representation**: The question asks the student to represent mathematical ideas using manipulatives, pictures, or symbols. "Can you show me with base ten blocks what 12 times 2 is?" How would you write this number using symbols?"	**What**: The question requires a short response, usually the result of a computation or the identification of a particular term. "What is $\frac{1}{2}$ of $\frac{1}{2}$?" "How many tens make a hundreds square?" "Which number has a 6 in the hundreds place?" **How**: The question asks the student to describe the methods used to perform a particular computational or manipulative procedure. "How did you get that answer?" "How could you add these numbers without counting on your fingers?" "How did you add those numbers with the blocks?" **Leading**: The question forces a particular way of thinking about a problem. It is focused on producing an answer to a problem rather than helping the student make sense of a problem. "$\frac{2}{4}$ is the same as what?" "Are there any clues in the problem that make you think of adding?" "What do we need to do next?"

Figure 2. Types of questions in preservice teachers' tutoring plans.

Erin: My questions could have been better during this tutoring session. I feel like most of my questions did not probe his thinking. He only had to "spit back information" or give me simple answers.

Hanna: I think that my questions did a good job of probing Jacob's mathematical thinking. I tried to use a wide variety of questions, as opposed to always asking "how" or "what." I could see that when I asked him "why" questions, they seemed to make him think the most. At that point, I tried to ask more questions that were geared this way. Just thinking about asking questions made me realize that this is not done enough in the classroom setting.

Conclusions

It is important to note that the issues discussed here — cognitive demands of mathematical tasks and types of questions posed to students — were *not* explicitly discussed with the preservice teachers in the seminar. These issues are certainly important to address with preservice teachers, but this investigation suggests the capabilities of preservice teachers before such discussions take place.

The majority of tasks designed by preservice teachers in this investigation required levels of cognitive demand that ranged from memorization to procedures with connections. Very few of the tasks required the type of thinking that is considered to be *doing* mathematics (Smith & Stein, 1998). This emphasis on lower levels of cognitive demand may have grown out of the original situation in which this seminar was conceived. That is, the group of participating fourth graders was determined by their results on the state exam, and the pretest and posttest administered during the first and last tutoring sessions were aligned with the state standards. Thus, the unstated goal for the preservice teachers was to help the students perform well on the posttest and then pass the next state exam. This familiar practice of "teaching to the test" may have denied students the opportunity to engage in more challenging tasks.

Table 2
Percent of Questions of Each Type Appearing in Preservice Teachers' Tutoring Plans

Preservice teacher	Conceptual					Procedural		
	Problem solving	Communication	Reasoning	Connection	Representation	What	How	Leading
Elementary Education majors								
Alice (n = 59)	5	5	29	10	19	10	12	10
Bethany (n = 68)	6	6	25	6	3	9	37	9
Cecily (n = 134)	3	1	27	2	16	10	13	28
Diana (n = 102)	7	4	13	3	13	10	15	36
Erin (n = 167)	5	5	17	2	7	28	11	25
Mathematics Education majors								
Frank (n = 27)	7	0	37	4	4	15	22	11
Gerald (n = 48)	4	6	23	4	6	6	27	23
Hanna (n = 29)	7	7	14	10	3	28	28	3
Irene (n = 138)	5	4	18	7	6	21	35	4
Double major								
Jillian (n = 116)	19	1	33	7	11	8	12	9
Art major								
Katy (n = 21)	5	9	29	9	19	5	14	9

Note: The variable n represents the number of questions in each teacher's tutoring plans.

The questions for students that preservice teachers included in their written plans revealed that they did have some understanding of the value of engaging students in problem solving, reasoning, communication, connections, and representation. Their written comments also showed that they appreciated the importance of asking probing questions and the difficulty of doing so. In actual teaching situations, though, the preservice teachers tended to ask more questions that focused on procedures than questions that focused on concepts. And, unfortunately, a substantial number of their questions focused on helping students arrive at answers to problems instead of helping students develop mathematical power.

The insights revealed in this study suggest at least two implications for the further development of preservice teachers' knowledge for teaching. First, it would be helpful to engage preservice teachers in activities and discussions that foster their understanding of the notion of cognitive demand of mathematical tasks (e.g., Smith, Stein, Arbaugh, Brown, & Mossgrove, 2004). The experiences in this seminar suggest that such discussions may be especially meaningful when preservice teachers are considering the impact of particular tasks on the learning of individual students for whom they have some responsibility. When preservice teachers have actually implemented various tasks with students, they are more ready to discuss the distinctions between teaching to a test and developing students' mathematical power.

Second, it would be useful to have preservice teachers examine the questions they pose to students through the framework used in this investigation (Figure 2). This examination could draw preservice

Table 3
Percent of Questions of Each Type Appearing in Preservice Teachers' Written Accounts of One Tutoring Session

Preservice teacher	Problem solving	Conceptual				Procedural		
		Communication	Reasoning	Connection	Representation	What	How	Leading
Elementary Education majors								
Alice (n = 12)	0	17	8	0	0	25	17	33
Bethany (n = 37)	3	5	14	5	0	22	19	32
Cecily (n = 104)	10	0	4	0	2	11	2	71
Diana (n = 36)	33	3	6	0	14	11	3	31
Erin (n = 23)	4	9	4	0	22	13	26	22
Mathematics Education majors								
Frank (n = 89)	0	2	1	0	10	24	3	60
Gerald (n = 21)	5	24	19	0	10	19	19	5
Hanna (n = 18)	28	0	17	0	11	11	6	28
Irene (n = 21)	0	0	5	19	10	14	14	38
Double major								
Jillian (n = 29)	24	0	7	0	0	34	21	14
Art major								
Katy (n = 22)	14	14	36	9	5	18	0	5

Note: The variable n represents the number of questions in each teacher's written account.

teachers' awareness to the various aspects of mathematical understanding addressed by particular types of questions. Again, the exercise would be most meaningful in the context of preservice teachers' interactions with students.

Overall, the preservice teachers learned important lessons through the tutoring experiences and discussion sessions. They learned about *learning* — "This class showed me how difficult it can be for some students to make the connections in their heads. I also learned how important it is to let students explain their own thinking and construct their own concepts because it is much more memorable and very empowering." They learned about *teaching* — "I learned that teaching math can be very frustrating and that it requires a lot of forethought. Doing research to find hands-on activities to help the student 'discover' new ideas is a great strategy. I would say that planning is key and patience is a must." And they learned about *themselves* — "I learned that when I tutor I often dominate the session. This is probably a characteristic that will also carry over to my classroom. Because I know this now, I can begin to work on it before I student teach."

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PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the *Journal* offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax them to 972-86-477-648. Questions concerning proposals and/or solutions can be sent e-mail to eisenbt@013.net. Solutions to previously stated problems can he seen at http://ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before March 15, 2010.

5092: *Proposed by Kenneth Korbin, New York, NY*

Given equilateral triangle ABC with altitude h and with cevian $\overline{CD}$. A circle with radius x is inscribed in ΔACD, and a circle with radius y is inscribed in ΔBCD with $x < y$. Find the length of the cevian $\overline{CD}$ if x, y and h are positive integers with $(x, y, h) = 1$.

5093: *Proposed by Worapol Ratanapan (student), Montfort College, Chiang Mai, Thailand*

$6 = 1 + 2 + 3$ is one way to partition 6, and the product of 1, 2, 3 is 6. In this case, we call each of 1, 2, 3 a **part** of 6.

We denote the maximum of the product of all **parts** of natural number n as $N(n)$.

As a result, $N(6) = 3 \times 3 = 9$, $N(10) = 2 \times 2 \times 3 \times 3 = 36$, and $N(15) = 3^5 = 243$.

More generally, $\forall n \in N$, $N(3n) = 3^n$, $N(3n + 1) = 4 \times 3^{n-1}$, and $N(3n + 2) = 2 \times 3^n$.

Now let's define $R(r)$ in the same way as $N(n)$, but each **part** of r is positive real. For instance $R(5) = 6.25$ and occurs when we write $5 = 2.5 + 2.5$.

Evaluate the following:

$$i) \qquad R(2e)$$

$$ii) \qquad R(5\pi)$$

5094: *Proposed by Paolo Perfetti, Mathematics Department, Tor Vergata University, Rome, Italy*

Let a, b, c be real positive numbers such that $a + b + c + 2 = abc$. Prove that

$$2(a^2 + b^2 + c^2) + 2(a + b + c) \geq (a + b + c)^2.$$

5095: *Proposed by Zdravko F. Starc, Vršac, Serbia*

Let F_n be the Fibonacci numbers defined by

$$F_1 = F_2 = 1, F_{n+2} = F_{n+1} + F_n (n = 1, 2, \cdots).$$

Prove that

$$\sqrt{F_{n-2}F_{n-1}} + 1 \le F_n \le \sqrt{(n-2)F_{n-2}F_{n-1}} + 1 \, (n = 3, 4, \cdots).$$

5096: *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

Let a, b, c be positive real numbers. Prove that

$$\frac{a}{b + \sqrt[4]{ab^3}} + \frac{b}{c + \sqrt[4]{bc^3}} + \frac{c}{a + \sqrt[4]{ca^3}} \ge \frac{3}{2}.$$

5097: *Proposed by Ovidiu Furdui, Cluj, Romania*

Let $p \ge 2$ be a natural number. Find the sum

$$\sum_{n=1}^{\infty} \frac{(-1)^n}{\left\lfloor \sqrt[p]{n} \right\rfloor},$$

where $\lfloor a \rfloor$ denotes the **floor** of a. (Example $\lfloor 2.4 \rfloor = 2$).

SSM Publication Guidelines

Journal Office:

Heather R. Rodriguez, Managing Editor
School Science and Mathematics Journal
Texas A&M University
4232 TAMU Harrington
College Station, TX 77843-4232

Circulation Data:

Reader: K-graduate leaders and teacher educators
Frequency of issue: 8 times per year
Copies per issue: 3001-4000
Sponsorship: Professional organization

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Time to review: 6-7 months
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Science, mathematics, and connections between science and mathematics for grades K-graduate and teacher education, especially science and mathematics articles that deal with assessment, attitudes, beliefs, curriculum, equity, research, translating research into practice, learning theory, alterative conceptions, philosophy and history of science, sociocultural issues, special populations, technology, nontraditional forms of instruction, and science/technology/society.

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1. An abstract not to exceed 200 words on a separate page
2. To maintain anonymity of the author(s), author(s) citing their own work should cite as follows:
   In text: Author (1999) found...
   On reference list: Author (2005). Journal Title. (Do not include title of article or volume and page #)
3. Graphics submitted as publication-ready copy on white background with black type. Each table or figure should be on a separate page at the end of the manuscript, with a note within the ms where the graphic should be placed. Use no smaller than 8-point font for text on figures; use no smaller than 11-point font for tables. Figures and tables should be no wider than 6.75 inches.

Manuscripts submitted for review will be evaluated on the following:

All manuscripts:

Relevence, timeliness, and significance
Addresses K through graduate classroom or teacher education issues
Explicitness, clarity, logicality, conciseness
Literature review
Theoretical/literature-based framework

Research manuscripts only:

Design and methodology
Analyses of data
Conclusions based on results
Results related to professional practice and literature
Enough information to enable replication (quantitative)

SCHOOL SCIENCE AND MATHEMATICS

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SCHOOL SCIENCE AND MATHEMATICS

Volume 110 • Number 2 • February 2010

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SSMA

Official Journal of the School Science and Mathematics Association, Founded 1901

School Science and Mathematics

Journal Office

(All publication matters except advertising and reprints)

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School Science and Mathematics (Print ISSN: 0036-6803, Online ISSN: 1949-8594) is published in January, February, March, April, September, October, November and December on behalf of the School Science and Mathematics Association by Wiley Subscription Services, Inc., a Wiley Company, 111 River St., Hoboken, NJ, 07030-5774. Periodical postage paid at Hoboken, NJ and additional offices.

Postmaster: Send all address changes to *School Science and Mathematics*, Journal Customer Services, John Wiley & Sons, Inc., 350 Main St., Malden, MA 02148-5020.

Information for Subscribers: *School Science and Mathematics* is published in eight issues per year. Subscription prices for 2010 are: Institutional Print & Online rate: US$250 (the Americas), US$250 (Rest of World), €180 (Europe) £153 (UK). Prices are exclusive of tax. Asia-Pacific GST, Canadian GST and European VAT will be applied at the appropriate rates. For more information on current tax rates, please go to www3.interscience.wiley.com/aboutus/journal_ordering_and_payment.html#Tax. The institutional price includes online access to the current and all online back files to January 1, 1997, where available. For other pricing options, including access information and terms and conditions, please visit www.interscience.wiley.com/journal-info.

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Production Editor: Alison McGonagle (ssm@wiley.com)

Electronic Access: This journal is available online at *Wiley InterScience*. Visit www.interscience.wiley.com to search the articles and register for table of contents and email alerts.

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ISSN: 0036-6803 (Print)
ISSN: 1949-8594 (Online)
Printed in the US by The Sheridan Group.

IN THIS issue

Research Articles

Web-Based Instruction on Preservice Teachers' Knowledge of Fraction Operations

Cheng-Yao Lin

This study determines whether web-based instruction (WBI) represents an improved method for helping preservice teachers learn both procedural and conceptual knowledge of fractions. The purpose was to compare the effectiveness of WBI with the traditional lecture in Mathematics Content and Methods for the Elementary School course. The results of this study suggest that the use of WBI in learning fractions is more effective. When compared with the traditional instruction, the WBI treatment results were significantly more effective for procedural and conceptual knowledge of fraction operations.

Mathematical Readiness of Entering College Freshmen: An Exploration of Perceptions of Mathematics Faculty

Jeffrey B. Corbishley, Mary P. Truxaw

The National Council of Teachers of Mathematics (2000) has set ambitious goals for the teaching and learning of mathematics that include preparing students for both the workplace and higher education. While this suggests that it is important for students to develop strong mathematical competencies by the end of high school, there is evidence to indicate that overall this is not the case. Both national and international studies corroborate the concern that, on the whole, U.S. twelfth grade students do not demonstrate mathematical proficiency (National Center for Educational Statistics, 1998, 1999, 2001a, 2001b, 2006), suggesting that students making the transition from high school to college mathematics may not be ready for its rigors. In order to investigate mathematical readiness of entering college students, this study surveyed mathematics faculty. Specifically, faculty members were asked their perceptions of average entering students' readiness related to relevant mathematical skills and concepts and the importance of the same skills and concepts as foundations for college mathematics. Results demonstrated that the faculty perceived that average freshman students are generally not mathematically prepared; furthermore, the skills and concepts rated as highly important — namely, algebraic skills and reasoning and generalization — were among those rated the lowest in terms of student competencies.

The Impact on Incorporating Collaborative Concept Mapping with Coteaching Techniques in Elementary Science Classes

Syh-Jong Jang

The purpose of this research was to evaluate a collaborative concept-mapping technique that was integrated into coteaching in fourth-grade science classes in order to examine students' performance and attitudes toward the experimental teaching method. There were two fourth-grade science teachers and four classes with a total of 114 students involved in the study. This study used a mixed method design, incorporating both quantitative, and qualitative techniques. The findings showed that the two teaching methods obtained significant difference with respect to students' test scores. Using collaborative concept mapping to learn science could increase the opportunity of discussion between peers, thus fostering better organization and understanding the content. In addition, coteaching could enable teachers to share their expertise with one another. It could facilitate the implementation of collaborative concept mapping and the construction of student's concept mapping. Team teachers' attitude could affect the students' learning performance. However, some of the students had negative views on drawing concept maps because they found it was troublesome to write down many words, difficult to draw and arrange proposition, and time-consuming. Coteachers' instant feedback and students' journal writing could guide and examine the students' concept maps to facilitate their cognitive learning.

Scientists and Science Educators Mentoring Secondary Science Teachers

Jerine M. Pegg, Heidi I. Schmoock, Edith S. Gummer

This paper examines secondary science teachers' perspectives of the role that mentoring by a scientist and science educator pair played in their professional development. Multiple data sources from three years

of a professional development project, including interviews, participant reflections, and a focus group, were used to examine the benefits, supporting characteristics, and challenges of the mentoring relationship. Results indicated that primary benefits of the mentoring included assistance in translating science content and inquiry-based pedagogy from the professional development into practice and breaking the isolation felt by secondary science teachers. Specific characteristics that were found to support the teachers in the mentoring relationship included: (1) mentors who were seen as objective, outside observers; (2) a sustained relationship with the mentors; and (3) accountability. Challenges included matching scientists' and science educators' content expertise with teachers' curriculum and the negotiation of roles and expectations between the teachers and mentors.

Web-Based Instruction on Preservice Teachers' Knowledge of Fraction Operations

Cheng-Yao Lin
Southern Illinois University Carbondale

This study determines whether web-based instruction (WBI) represents an improved method for helping preservice teachers learn procedural and conceptual knowledge of fractions.. The purpose was to compare the effectiveness of web-based instruction (WBI) with the traditional lecture in mathematics content and methods for the elementary school course. The results of this study suggest that the use of WBI in learning fractions is more effective. When compared with the traditional instruction, the WBI treatment results were significantly more effective for procedural and conceptual knowledge of fraction operations.

Fractions are difficult but crucial in mathematics learning. Quantities represented by natural numbers are easily understood. For example, we can count and say how many apples are in a bag. But fractions cause difficulty for most people because they involve relations between quantities. In England, the National Curriculum for England suggests that pupils should be taught number operations and the relationships between them (National Curriculum for England, 2008). In the United States, the National Council of Teachers Mathematics'(NCTM, 2006) Curriculum Focal Points recommended in grade 3, to develop an understanding of fractions and fraction equivalence; in grade four, to develop an understanding of decimals, including the connections between fractions and decimals; in grade five, to develop an understanding of and fluency with addition and subtraction of fractions and decimals; and in grade six, to develop an understanding of and fluency with multiplication and division of fractions and decimals. Therefore, a competent teacher should know the goal of curriculum standards about fractions very well. In addition, teachers should be well prepared in order to help students learn fractions.

Unfortunately, several research studies have found that teachers and preservice teachers have difficulties with the concepts of fraction (Ball, 1990; Behr, Khoury, Harel, Post, & Lesh, 1997; Cramer, Post, & del Mas, 2002; Davis & Thipkong, 1991; Flores, 2002; Izsak, 2008; Rizvi & Lawson, 2007; Simon, 1993; Tirosh, 2000). For example, Ball found that preservice elementary teachers had significant difficulty with the meaning of division of fractions. Similarly, on the study of the prospective elementary teachers' knowledge of division, Simon concluded that preservice elementary teachers have a serious shortcoming in their understanding of division by modeling of situations. The preservice elementary teachers were unable to think flexibly and consciously about division as partitive and quotitive. In addition, further research found that preservice teachers experience difficulty in explaining fractions to children and are unable to explain why algorithms work (Chinnappan, 2000; Lubinski, Fox, & Thomason, 1998; Selden & Selden, 1997). Ma (1999) found that many American teachers were unable to perform a calculation such as $1\ ^3/_4 \div\ ^1/_2$. Those who were successful (9 out of 21 teachers interviewed) relied on the rule to invert the second fraction and then multiply. None of them provided any rational understanding of this rule. In contrast, all of the 72 Chinese teachers computed correct and complete answers to the problem. Most teachers (90%) were able to provide one or more correct stories to explain the meaning of division by fractions.

According to NCTM (2000), technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning. Research on technology integration in mathematics education has provided strong evidence that using computers in the classroom can benefit students' learning in mathematics (Isiksal & Askar, 2005; Olkun, Altun, & Smith, 2005; Sinclair, 2004). Okolo, Bahr, and Reith (1993) found that students who use appropriate technology persist longer, enjoy learning more, and demonstrate gains in mathematics performance. Similarly, Suh, Moyer, and Heo (2005) found that virtual manipulatives could facilitate the connection between conceptual and procedural understanding by capitalizing on graphic/nonlinguistic features of the virtual fraction manipulatives. Reimer and Moyer (2005) found that using virtual manipulatives improved students' achievement in both conceptual and procedural knowledge in learning about fractions.

Research has shown that the effective use of multimedia or interactive web-based modules can increase student learning (Aberson, Berger, Healy, & Romero, 2003; Bliwise, 2005; Erwin & Rieppi, 1999; Fletcher-Flinn & Gravatt, 1995; Forsyth & Archer, 1997; Hurlburt, 2001; McNeil & Nelson, 1991). Aberson et al. evaluated a web-based interactive tutorial used to present hypothesis-testing concepts. The results indicate that students who used the tutorial performed better on a quiz than students who completed the standard laboratory, supporting the effectiveness of this freely available online tutorial. Similar, Bliwise suggests that web-based tutorials improved student learning on statistics.

Few studies have addressed the question of whether the use of computers hampers or improves preservice teachers' conceptual knowledge and procedural knowledge in fractions. The purpose of this study was to determine whether web-based instruction (WBI) represents an improved method for helping preservice teachers learn procedural and conceptual knowledge of fractions (Hiebert & Lefevre, 1986). This research paralleled the earlier work of Hurlburt (2001) and Bliwise (2005) by using web-based tutorials in learning mathematics. Hurlburt compared lectlet-based distance education with traditional education for four semesters by simultaneously teaching two sections of introductory statistics: one lectlet-based and the other in the traditional format. A lectlet is a short Web-streamed audio lecture synchronized to an interactive text–graphics display. The results showed that students who learned statistics using multimedia format perform better than those in traditional education settings. Similarly, Bliwise compared learning outcomes of students who attended one of two classes that offered the tutorials to students as an extra-credit course option with those who attended a lecture-only class. The results indicate that web-based tutorials can be an effective supplement to class lectures for enhancing student learning.

Theoretical Framework

The first theoretical framework guiding this research is constructivism. Constructivist theory states that students' experiences, collaboration, and self-construction of knowledge is relevant to instruction. Constructivist views assert that learning is the active process of constructing rather than passively acquiring knowledge, and instruction is the process of supporting the knowledge constructed by the learners rather than the mere communication of knowledge (Duffy & Cunningham, 1996; Honebein, Duffy, & Fishman, 1993; Jonassen, 1999). von Glasersfeld (1995) indicates, in relation to the concept of reality, "It is made up of the network of things and relationships that we rely on in our living, and on which, we believe, others rely on, too" (p. 7). In addition, constructivist theory encourages students to seek to make sense out of the to-be-learned information (Bruner, 1996; Jonassen, Peck, & Wilson, 1999).

The second theory guiding this research is procedural and conceptual knowledge. Procedural knowledge is knowing *how-to* (Hiebert & Lefevre, 1986). For example, students who know how to apply the rule to do fraction division are exhibiting procedural knowledge. Teaching for *procedural knowledge* means teaching students to physically solve a problem through the manipulation of mathematical skills, such as procedures, rules, formulae, algorithms and symbols used in mathematics (Skemp, 1987). Conceptual knowledge is knowing *why* (Hiebert & Lefevre). For example, if students know why they "invert and multiply" fractions in division, they are exhibiting conceptual knowledge. Teaching for *conceptual knowledge*, on the other hand, means to teach students to show understanding of mathematical concepts by being able to interpret and apply them correctly to a variety of situations, as well as the ability to translate these concepts between verbal statements and their equivalent mathematical expressions. Star (2005) defined conceptual knowledge as both superficial and deep knowledge, whereas procedural knowledge has been primarily defined as superficial. Baroody, Johnson, and Feil (2007) describe development of knowledge and understanding as a process that increases knowledge of these kinds, creating richer connections and ending up with well-connected procedural and conceptual knowledge. Web-based instruction provides an opportunity to connect both procedural knowledge and conceptual knowledge. For the fraction 1/6 + 3/5, the Java applet will show a diagram of 1/6 and 3/5. Next, it will ask students to rename 1/6 and 3/5 so that the denominators are the same. If the student keys in the correct answer, then it allows students to do addition (see Figure 1). With several practice problems, students not only know how to solve 1/6 + 3/5, but also know why they have to find the common denominators in order to do the operations.

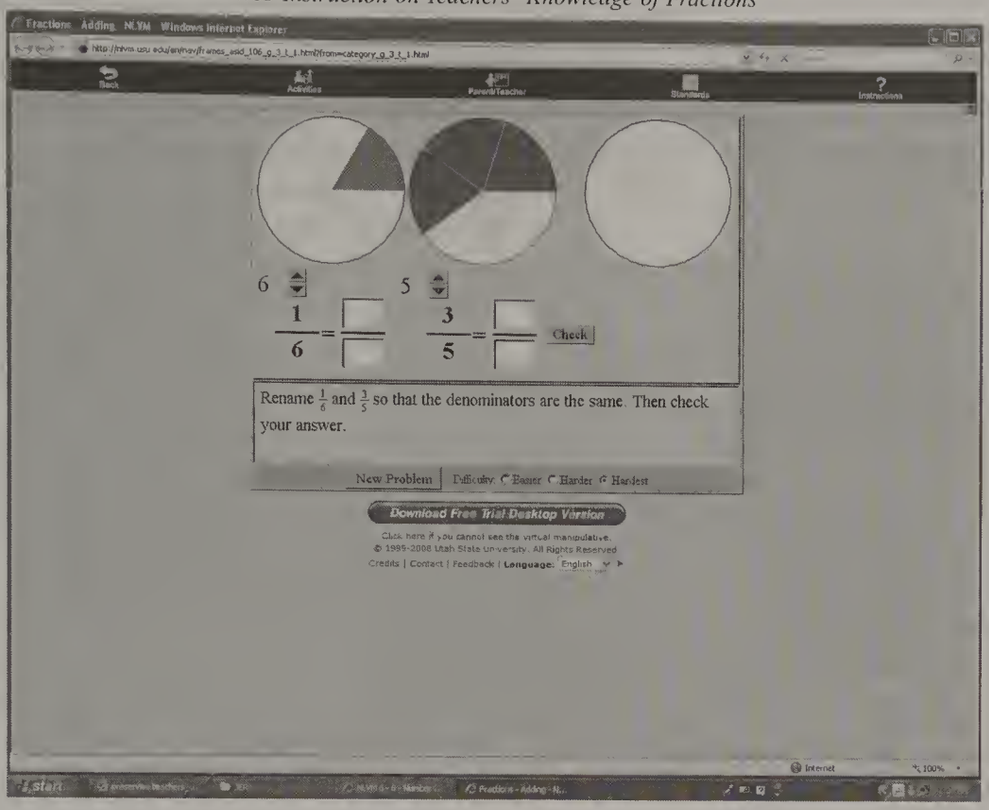

Figure 1. Example of the interactive websites.

Research Questions

The purpose of this study was to compare the effectiveness of web-based and traditional instruction on preservice elementary teachers' procedural knowledge and their conceptual knowledge of fractions. The specific questions investigated in the study were:

1. Are there significant differences in pretest, posttest and retention on fraction procedural knowledge (FPK) between preservice teachers in web-based instruction and traditional instruction?
2. Are there significant differences in pretest, posttest and retention on fraction conceptual knowledge (FCK) between preservice teachers in web-based instruction and traditional instruction?

Method

Subjects

The sample included 48 university students (aged 18 to 21 years; M = 19.11) attending Mathematics Content and Methods for the Elementary School course at the College of Education. Ninety-four percent of the participants were younger than age 25, and approximately 90% were female (40 women, 4 men). The minimum number of math courses required by the university is four. All the participants were in the teacher education program and had completed two prerequisite courses. The Mathematics Content and Methods for the Elementary School course is a three-hour lecture per week and a required course for all undergraduate students in the teacher education program. The fraction unit is covered during the spring semester. One class was randomly assigned to the web-based instruction (n = 24), while the other group formed the traditional instruction (n = 24). Students in web-based instruction were instructed with web-based resources related to fraction concepts, while students in traditional instruction received traditional methods in learning fraction concepts. All students were taught by the same instructor, and both groups received six weeks of instruction or 18 hours in this study.

Instrument

The instrument format was an open-ended test and consisted of two major areas: (a) FPK and (b) FCK. The instrument contained a total of 16 questions. Eight dealt with fraction procedural knowledge, and another eight dealt with fraction conceptual knowledge.

The test on fraction concept was adapted from Cramer et al. (2002) and Ma (1999). The researcher modified this test to provide more emphasis on procedural and conceptual knowledge. The survey instruments were piloted with 25 preservice teachers who were enrolled in a mathematics method course. Internal consistency reliability coefficients (Cronbach's

alpha) were computed for each subscale after Time 1 administration of the questionnaire. The reliability (Cronbach's alpha) of the tests were found to be FPK = 0.80, and FCK = 0.80 in this study. The following two items exemplify respective items included on the test.

1. Procedural knowledge item: Solve the problem $\frac{3}{4}\times\frac{2}{3}=?$

2. Conceptual knowledge item: Imagine that you are teaching multiplication with fractions. To make this meaningful for kids, what would you say would be a good story or model for $\frac{3}{4}\times\frac{2}{3}=?$

Sixteen test items were used as both pretest and posttest measures of students' learning of fraction operation concepts. Eight out of 16 test items were procedural knowledge, and the remaining eight items were conceptual knowledge. A complete and correct answer was worth 2 points. A partial answer was worth 1 point. An incorrect answer was worth 0 point. The test was specifically designed to measure possible fraction concepts in areas related to: (1) fraction addition: item 1, item 2, item 3, and item 4; (2) fraction subtraction: item 5, item 6, item 7, and item 8; (3) fraction multiplication: item 9, item 10, item 11, and item 12; (4) fraction division: item 13, item 14, item 15, and item 16; and the procedural knowledge items are item 1, 3, 5, 7, 9, 11, 13, and 15. The conceptual knowledge items are item 2, 4, 6, 8, 10, 12, 14, and 16 (see Appendix).

Treatment

There were two groups of students: one web-based instruction and one traditional instruction. Both groups received six weeks of instruction (18 hours). Four topics were discussed in Mathematics Content and Methods for the Elementary School course: fraction addition, fraction subtraction, fraction multiplication, and fraction division. Each topic was connected to the goals of the *Principles and Standards for School Mathematics* (NCTM, 2000).

Students in the web-based instruction received instruction using Internet computer programs on the mathematics content. Based on the constructivist theory, students discovered and constructed their knowledge by using web-based programs. Web-based programs facilitate student interaction and involvement. They spent the entire class time using WBI. They attended lectures as well, and then did extra computer web work. When first developed, two mathematic education experts and the author selected and reviewed websites that were comprehensive, well-organized, dynamic, interactive, hands-on, and ready to use by teachers for mathematics teaching in the classroom. For example, interactive web sites such as the National Library of Virtual Manipulative (National Library of Virtual Manipulative, 2007) and Illuminations were selected (see Figure 1). Next, the dynamic, animated, and interactive web-based resources were shown to students. Interactive web-based instruction was developed as research suggests that animated demonstration may be more efficiently processed by learners than without animated demonstration (Wender & Muehlboeck, 2003). Therefore, students in the web-based instruction had more tasks, making use of dynamic animated representations on computers. The web-based instruction module is shown in Figure 2.

The selected Internet computer programs are interactive and can illustrate a concept through attractive animation and demonstration. In addition, they allow students to progress at their own pace and to work individually or problem solve in a group. They provide immediate feedback, letting students know whether their answer is correct. If the answer is not correct, the program shows students how to correctly answer the question, and this helps them strengthen their procedure knowledge of fractions (see Figure 1). For the conceptual knowledge of fractions, they could discover many solutions (Becker & Shimada, 1997; Hashimoto & Becker, 1999) to solve a problem such as $^1/_2 \div {}^3/_4$ on the Internet. In addition, they could find a story or a meaning to explain a problem such as $^1/_2 \div {}^3/_4$ on the Internet computer programs.

The traditional instruction method in this study included lectures given by a teacher, use of textbooks and other materials, and a clear explanation of procedural knowledge and conceptual knowledge of fractions to students. The teacher demonstrated fraction models and a review of the textbook topics. The student materials included a text (Van de Walle, 2007). They spent their class time using hands-on and manipulative activities. The traditional instruction group spent the same time on the same concepts as the web-based group. Preservice teachers were shown pictures of fractions, had to find many ways to answer, and had them explain their answer (Becker & Shimada, 1997; Hashimoto & Becker, 1999). However, they did not have any tasks that made use of

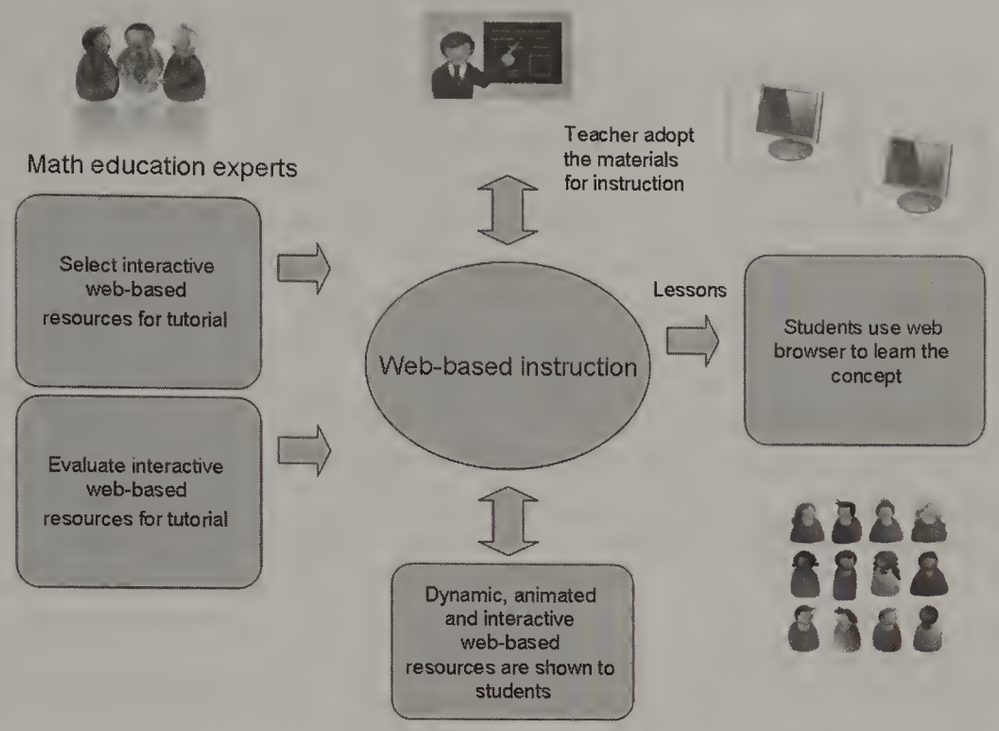
Math education experts
Teacher adopt the materials for instruction
Select interactive web-based resources for tutorial
Evaluate interactive web-based resources for tutorial
Web-based instruction
Lessons
Students use web browser to learn the concept
Dynamic, animated and interactive web-based resources are shown to students

Figure 2. Web-based instruction model.

Table 1
Web-Based Instruction versus Traditional Instruction

Method	Web-based instruction (n = 24)	Traditional instruction (n = 24)
Instructional content	The instruction included lessons on fraction addition, fraction subtraction, fraction multiplication, and fraction division.	The instruction included lessons on fraction addition, fraction subtraction, fraction multiplication, and fraction division.
Forms of instruction	The students worked in pairs on a computer.	The students worked in groups without using any computers.
Learning environments	Students received instruction using a computer-based, online learning system.	Students did not use any computer-assisted instructional programs or software.
Homework assignments	The students completed a series of homework assignments on a computer.	The students completed a series of homework assignments without using any computers.

dynamic representations on computers (see Table 1). They did not use computers for practice or to learn on their own. That is, students in the control group were asked to do the same types of tasks as the experimental group except for use of the web-based resources to construct their knowledge. The time on tasks for traditional instruction was the same as web-based instruction. The attendance rates in the traditional instruction group were the same as the web-based group. The traditional instruction group and web-based group met at different times. Both the traditional instruction group and web-based group had the same content area of conceptual and procedural knowledge. There were no social interactions between groups or within groups. There was a lab specifically for the WBI students. The lecture-based students could not attend this lab. They met in a different classroom.

Data Analysis

A repeated-measures analysis of variance (ANOVA) was used to test differences between groups (web based vs. traditional), across time (Time 1 vs. Time 2 vs. Time 3), and group-by-time interaction effects. In addition to tests of the main effects (group and time) and interaction effects, post hoc contrasts for each subtest were also calculated. A *t*-test was used to examine pretreatment differences (Time 1) between the traditional instruction students and web-based instruction students. The Time 1 test was administered the day before the WBI lesson. Time 2 test measures were collected immediately after the treatment and Time 3 collected four weeks after the treatment.

Results

Based on the data obtained by the Fraction Knowledge Test (FKT), the students' mean (M) and standard deviations (SDs) for pre–posttest scores for procedural knowledge and pre–posttest scores for conceptual knowledge responses for web-based and traditional instructions were found as shown in Table 2.

Internal consistency reliability coefficients (Cronbach alphas) were computed for each subscale. Coefficients were FPK = 0.80 and FCK = 0.82. Nunnally (1979) reported that 0.70 is adequate reliability for research purposes. Both subscales FPK and FCK exceeded the level of 0.70 reliability.

In order to identify students' prior knowledge of fraction concepts, the Fraction Knowledge Test was administered to web-based and traditional instructions before treatment. Analysis of independent *t*-test results showed that there was no significant mean difference between the groups for FPK, $t(48) = 1.697$, $p > 0.05$, and FCK, $t(48) = 1.554$, $p > 0.05$. After the treatment, a repeated-measures ANOVA was used to test the differences between groups over three time periods.

Table 2 shows that the mean of pretests on procedural knowledge ($M = 12.64$, $SD = 2.51$) are significantly higher than the mean of pretests on conceptual knowledge ($M = 6.14$, $SD = 3.06$). This finding is consistent with Ma (1999), who found that teachers were able to do the calculation of fraction division; however, they were unable to explain why algorithms work.

Fraction Procedural Knowledge Findings and Discussion

To test for FPK differences between groups over three time periods, an ANOVA with repeated measures on one factor (time) was computed (see Table 3).

A repeated measures one-way ANOVA revealed that the main group effects result was significant, $F(1, 46) = 7.769$, $p < 0.05$, indicating that group mean scores (when averaged over time) differ from one group to the other. There were significant differences in fraction procedural knowledge between the three times of measurement, $F(1, 46) = 30.443$, $p < 0.05$, which indicates

Table 2
Fraction Knowledge Mean Scores

		T1		T2		T3	
		M	*SD*	*M*	*SD*	*M*	*SD*
Traditional instruction	Procedural knowledge	12.41	2.60	14.21	1.02	13.96	0.91
	Conceptual knowledge	5.95	2.92	9.04	2.49	8.58	2.12
Web-based instruction	Procedural knowledge	12.87	2.46	15.38	1.27	15.29	1.30
	Conceptual knowledge	6.33	3.25	13.67	2.44	13.21	2.10
Total	Procedural knowledge	12.64	2.51	14.79	1.28	14.62	1.29
	Conceptual knowledge	6.14	3.06	10.35	4.14	9.89	3.95

Table 3
ANOVA Summary Table for Fraction Procedural Knowledge

Source	*df*	*SS*	*MS*	*F*	*p*
Group	1	11.669	11.669	7.769	0.008*
Residual between	46	69.088	1.502		
Time	1	136.792	136.792	30.443	0.000*
Group × Time interaction	1	5.181	5.181	1.153	0.289
Residual within	46	206.694	4.493		
Contrasts					
Group: Time 1 to Time 2	1	221.021	221.021	33.449	0.000*
Group: Time 1 to Time 3	1	1.333	1.333	9.684	0.003*
Group: Time 2 to Time 3	1	41.16	41.16	4.21	0.051

* Significant at $p < 0.05$ alpha.

that students' scores changed over time. Gains in scores were also retained over time. However, the group-by-time interaction was not significant, $F(1, 46) = 1.15$, $p > 0.05$ (see Table 3). That is, web-based instruction and traditional instruction did not differ in their responses over time.

Preplanned contrasts to test for group differences across time demonstrated that students receiving web-based instruction treatment scored significantly higher at Time 2 than did their traditional instruction counterparts, $F(1, 46) = 33.449$, $p < 0.05$. The interaction between Time 1 and Time 2 demonstrated the strength of the web-based instructional methods on FPK (see Figure 3). The effect size for procedural knowledge ($d = 0.61$) are considered medium (Cohen, 1988). However, the interaction between Time 2 and Time 3 demonstrated the weakness of the web-based instructional methods on FPK (see Table 3). The effect size for procedural knowledge ($d = 0.15$) is considered weak (Cohen).

Fraction Conceptual Knowledge Findings and Discussion

The findings for the FCK of the study were similar to those of the FPK. The main group effects' result was significant, $F(1, 46) = 53.883$, $p < 0.05$, indicating that group mean scores (when averaged over time) differ from one group to the other.

The significant test for time main effects was a significant time, $F(1, 46) = 80.491$, $p < 0.05$, which indicates that students' scores changed over time.

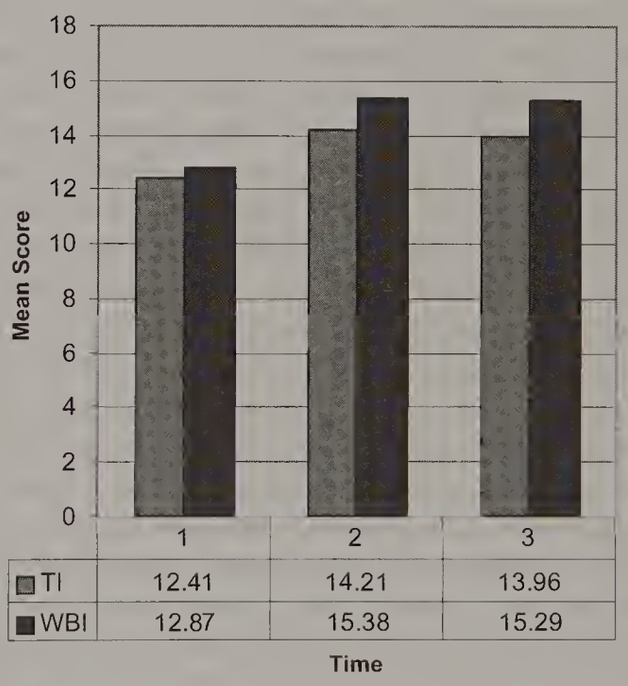

Figure 3. Fraction procedural knowledge information.
Note. TI = traditional instruction; WBI = web-based instruction.

Gains in scores were also retained over time (see Table 4). A group-by-time interaction was detected, which indicated that there was a basic tendency of conceptual knowledge growth in two groups. The web-based instruction showed tremendous growth between Time 1 and Time 2.

Table 4
ANOVA Summary Table for Fraction Conceptual Knowledge

Source	*df*	*SS*	*MS*	*F*	*p*
Group	1	247.521	247.521	53.883	0.000*
Residual between	46	211.310	4.594		
Time	1	511.720	511.720	80.491	0.000*
Group × Time interaction	1	312.50	312.500	49.155	0.000*
Residual within	46	292.440	6.357		
Contrasts					
Group: Time 1 to Time 2	1	850.083	850.083	86.673	0.000*
Group: Time 1 to Time 3	1	10.083	10.0830	33.329	0.000*
Group: Time 2 to Time 3	1	30.05	30.05	3.11	0.040

* Significant at $p < 0.05$ alpha.

Preplanned contrasts of group differences across time demonstrated that students receiving the web-based instruction treatment scored significantly higher, $F(1, 46) = 49.155$, $p < 0.05$, at Time 2 than did their traditional instruction counterparts (see Figure 4 and Table 4). Thus, web-based instruction methods were significantly more effective across instruction to Time 2. This is consistent with findings reported by Reimer and Moyer (2005). The interaction between Time 1 and Time 2 demonstrated the strength of the web-based instructional methods on FCK (see Figure 4). The group-by-time interaction was significant, $F(1, 46) = 49.16$, $p < 0.05$. That is, web-based and traditional instruction differs in their responses over time. The effect size for conceptual knowledge ($d = 1.71$) is considered large (Cohen, 1988). However, the interaction between Time 2 and Time 3 demonstrated the weakness of the web-based instructional methods on FCK (see Table 4). The effect size for procedural knowledge ($d = 0.17$) is considered weak (Cohen).

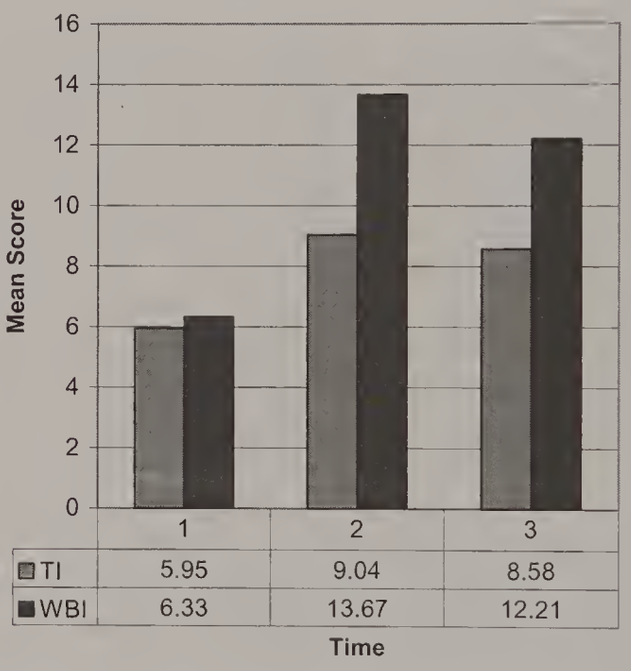

Figure 4. Fraction conceptual knowledge information.
Note. TI = traditional instruction; WB = web-based instruction.

Discussion and Conclusions

Significance of Findings

The purpose of this study was to determine whether a web-based instruction (WBI) represents an improved method for helping preservice teachers learn fractions in procedural and conceptual knowledge (Hiebert & Lefevre, 1986). The results suggested that web-based instruction provided an efficient method in providing students with the opportunity to promote their procedural and conceptual knowledge on fractions, which is consistent with the finding reported by Suh et al. (2005), Hurlburt (2001), and Bliwise (2005).

In this study, we found that the computer program for the web-based instruction helps to capture the preservice teachers' attention because the programs are interactive and learner centered. It is focused on the

learner rather than the teacher, and on learner-active mastery of material through interactive learning and teaching. This finding is consistent with Iskander and Curtis (2005) and Schorr and Goldin (2008), who found computer-assisted instruction's simulation improves mathematics learning.

Second, we found that the interactive websites used for web-based instruction provide a dynamic and animated tool for improving students' visual and conceptual abilities in learning mathematics concepts. They afford the design of activities to permit students to explore complex and dynamic relationships in the subject matter. For example, when we take 1/6 + 3/5, the computer animation helps students to find the same common denominators. Next, it helps students to do the addition. In addition, the dynamic and animated tool helps students to create a good story. For example, when we take $^1/_2 \div {}^1/_4$, the dynamic and animated tool helps students to visualize how many $^1/_4$ goes into $^1/_2$. Based on this understanding, they can tell a good story about $^1/_2 \div {}^1/_4$. This finding is consistent with Wender and Muehlboeck (2003), who found that animated demonstration helped students learn mathematics.

Third, this study has found that web-based instruction improves instruction for preservice teachers because they receive immediate feedback, and the programs let them know whether their answer is correct. Interactive websites move at their pace, and usually do not move ahead until they have mastered the skill. For example, when we take 1/6 + 3/5, if students give the wrong answer of the common denominators, the computer program will receive immediate feedback. It will not let students to do the operation until they find the correct denominators. This finding is consistent with Fuchs, Fuchs, Hamlet, and Powell (2006) and Fuchs, Fuchs, Hamlett, and Appleton (2002).

Implications for Learning and Instruction

This study has several implications for preservice teachers' mathematics preparation. First, teacher education programs must provide preservice teachers with the opportunity to strengthen their content knowledge. Also, preservice mathematics teacher education programs must provide experiences to help preservice teachers' fluency in procedural knowledge and understanding in conceptual knowledge of fractions. Mathematics methods courses that focus on procedural and conceptual knowledge in elementary mathematics are needed. The use of interactive websites may help preservice teachers not only master skills in procedural knowledge, but also help them understand the conceptual knowledge.

Second, the web-based instruction is successful in providing situated learning in the classroom, in teaching difficult concepts, and in transferring theory into practice.

For example, in teaching fraction addition with web-based instruction, the dynamic presentations help students not only know how to apply the rule to do fraction addition, but also know why they have to find the common denominator in order to do the operation. It also helps students to create a good story based on their own understanding of fraction operations.

Third, web-based instruction provides an opportunity to explore in mathematics. The computer-based exploration in mathematics is a powerful tool not only to assist preservice teachers' mathematical understanding, but also to facilitate deep understanding of both procedural and conceptual knowledge (Star, 2005). It can help to create richer connections and result in well-connected procedural and conceptual knowledge. Rich connections between procedural and conceptual knowledge can enhance students' mathematical competence.

Limitations and Recommendations

However, some major limitations of the study should be noted. The first limitation of this research project was the relatively short period of time of instruction. There were only six weeks of instruction instead of the whole academic semester. Future studies should add more time to the instruction. The second limitation of this research project was that the web-based instruction emphasized only topics on fractions. Future studies could add more topics such as measurement, geometry and data analysis. The third limitation of this research project was that 48 subjects were used. A larger number would permit greater generalization. Finally, this research project used only elementary education students. This might affect its generalizability to other majors. Lastly, subjects from only one institution and one instrument were used in the investigation. The generalizability of the observed findings to other instruments or contexts should be established. Future studies could involve more institutions and compare the outcomes.

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Author's Notes

Keywords: mathematics education; technology; computers; interactive websites; Internet; preservice teacher; teacher education; fraction operations.

Appendix

Fraction Knowledge Test: Operation Name:_____
Section:_____
Date:_____

1. How do you solve a problem like $\frac{1}{4}+\frac{2}{3}=?$

2. Imagine that you are teaching addition with fractions. To make this meaningful for kids, what would you say would be a good story or model for $\frac{1}{4}+\frac{2}{3}=?$

3. How do you solve a problem like $1\frac{2}{3}+\frac{3}{4}=?$

4. Imagine that you are teaching addition with fractions. To make this meaningful for kids, what would you say would be a good story or model for $1\frac{2}{3}+\frac{3}{4}=?$

5. How do you solve a problem like $\frac{3}{4}-\frac{2}{3}=?$

6. Imagine that you are teaching subtraction with fractions. To make this meaningful for kids, what would you say would be a good story or model for $\frac{3}{4}-\frac{2}{3}=?$

7. How do you solve a problem like $4\frac{3}{8}-3\frac{3}{4}=?$

8. Imagine that you are teaching subtraction with fractions. To make this meaningful for kids, what would you say would be a good story or model for $4\frac{3}{8}-3\frac{3}{4}=?$

9. How do you solve a problem like $\frac{3}{4}\times\frac{2}{3}=?$

10. Imagine that you are teaching multiplication with fractions. To make this meaningful for kids, what would you say would be a good story or model for $\frac{3}{4}\times\frac{2}{3}=?$

11. How do you solve a problem like $1\frac{1}{4}\times 2\frac{2}{3}=?$

12. Imagine that you are teaching multiplication with fractions. To make this meaningful for kids, what would you say would be a good story or model for $1\frac{1}{4}\times 2\frac{2}{3}=?$

13. How do you solve a problem like $\frac{1}{4}\div\frac{1}{3}=?$

14. Imagine that you are teaching division with fractions. To make this meaningful for kids, what would you say would be a good story or model for $\frac{1}{4}\div\frac{1}{3}=?$

15. How do you solve a problem like $2\frac{3}{4}\div\frac{2}{3}=?$

16. Imagine that you are teaching division with fractions. To make this meaningful for kids, what would you say would be a good story or model for $2\frac{3}{4}\div\frac{2}{3}=?$

Mathematical Readiness of Entering College Freshmen: An Exploration of Perceptions of Mathematics Faculty

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The National Council of Teachers of Mathematics has set ambitious goals for the teaching and learning of mathematics that include preparing students for both the workplace and higher education. While this suggests that it is important for students to develop strong mathematical competencies by the end of high school, there is evidence to indicate that overall this is not the case. Both national and international studies corroborate the concern that, on the whole, US 12th grade students do not demonstrate mathematical proficiency, suggesting that students making the transition from high school to college mathematics may not be ready for its rigors. In order to investigate mathematical readiness of entering college students, this study surveyed mathematics faculty. Specifically, faculty members were asked their perceptions of average entering students' readiness related to relevant mathematical skills and concepts, and the importance of the same skills and concepts as foundations for college mathematics. Results demonstrated that the faculty perceived that average freshman students are generally not mathematically prepared; further, the skills and concepts rated as highly important — namely, algebraic skills and reasoning and generalization — were among those rated the lowest in terms of student competencies.

The National Council of Teachers of Mathematics (NCTM, 2000) has set ambitious goals for the teaching and learning of mathematics that include preparing students for both the workplace and higher education. While this suggests that it is important for educators to ensure that students develop strong mathematical competencies by the end of their high school experiences, there is evidence to indicate that overall, this is not the case. Both national and international studies corroborate the concern that, on the whole, U.S. 12th grade students do not demonstrate mathematical proficiency (National Center for Educational Statistics [NCES], 1998, 1999, 2001a, 2001b, 2006; National Commission on Mathematics and Science Teaching for the 21st Century, 2000; US Department. of Education [USDoE], 1998).

Concerns about mathematical competence are particularly important for students who are college bound. For example, the report of the Mathematical Association of America (MAA) *Curriculum Foundations Project* notes that "few educators would dispute that students who can think mathematically and reason through problems are better able to face the challenges of careers in other disciplines — including those in non-scientific areas" (Ganter & Barker, 2004, p. 1). The report from MAA project raises issues related to high school mathematics instruction (Marcus, Fukawa-Connelly, Conklin, & Fey, 2007); in particular, there are questions related to readiness to perform successfully in college mathematics. While there are many studies that report high school mathematics achievement data (e.g., Burrill, 1998; Martin & Mullis, 2005; NCES, 1998, 1999, 2001a, 2001b, 2006; Schmidt, Wang, & McKnight, 2005; USDoE, 1998), research that connects expectations for college mathematics and high school students' competencies appears to be limited (LaBerge, Zollman, & Sons, 1997; Marcus et al.). Therefore, this study provides a "next step" as it seeks to uncover expectations and a sense of readiness of those who teach students as they transition from high school to college mathematics. This leads to the two research questions:

- What perceptions do college mathematics instructors have of mathematical readiness of average incoming freshmen students?
- Which mathematical topics do college mathematics instructors perceive as being important for success in college-level mathematics?

This paper will describe a study that surveyed college mathematics instructors at public colleges and universities in a northeastern state in the United States in order to answer the research questions. Along with results, implications for high school mathematics teachers, college mathematics faculty, and mathematics education researchers will be presented.

Review of Literature

Definition of Terms

A definition for *mathematical readiness* was developed by building on Reschke's (2005) definition for *school readiness* (i.e., "the degree to which a child is predicted to succeed in the school environment," p. 1). Success in the school environment means the ability to pass the required coursework. For this study, *mathematical readiness* was defined as *the degree to which a student is predicted to succeed in the college environment in mathematics*. Readiness of the average freshman was determined by studying faculty perception of ability. When students were perceived as having certain abilities related to specific skills, it gave insights as to the readiness of the students in terms of those skills. To further elucidate the notion of mathematical readiness, Lutfiyya's (1998) description of *mathematical thinking* was drawn upon. Lutfiyya describes mathematical thinking as the skills necessary to "understand ideas, discover relationships among ideas, draw or support conditions about the idea and their relationships, and solve problems involving their ideas" (pp. 55-56), including the following categories: generalization, induction, deduction, symbolism, logical thinking, and mathematical proof (Lutfiyya). These ideas help clarify that mathematical readiness includes having ability in specific mathematical skills.

Mathematical Knowledge and Achievement

When considering mathematical readiness, it is important to explore how mathematical thinking and knowledge may be developed. Gray, Pinto, Pitta, and Tall (1999) provide a useful model for how mathematical knowledge is constructed — that is, from simplistic ideas to more complex ones. Students who study mathematics from a simplistic perspective may view the subject only in terms of symbols and computation — for example, doing many of the same type of problem repeatedly. The transition from a simple to a more complex view involves making use of mathematical properties in order to deductively construct concepts. Being able to adapt mathematical concepts and to think in symbolic ways are two signs of higher level mathematical thinking (Gray et al.).

While it may be challenging to measure student mathematical thinking, assessments of mathematical achievement can provide indicators of thinking, and, in turn, of potential mathematical readiness. On a national level, the National Assessment for Educational Progress (NAEP) provides measures of student achievement, and, indirectly, student mathematical thinking. NAEP results show some reason for concern — for example, in 2005, *less than one quarter* of US 12th-grade students who were tested performed at or above the *proficient* level in mathematics, and *only 2%* achieved at the *advanced* level (NCES, 2006). The results from NAEP analyze students as a whole, regardless of course levels, and therefore would show strong indication as to the ability of the average student nationally. International comparisons are not encouraging either; the results of the Third International Mathematics and Science Study 1995 study (the most recent time that 12th-grade students were tested in mathematics) showed US 12th-graders scoring below 14 of 21 participating countries (Martin & Mullis, 2005). Clearly, there are reasons for concern related to mathematical achievement, and, in turn, readiness for college-level mathematics. These data suggest a need to look carefully at mathematics curriculum and instruction in US schools.

Mathematics Curriculum and Instruction

Disappointing results in national and international assessments have provoked mathematics educators and researchers to analyze current mathematics curricula to see if it may be a factor in mathematics achievement. Research has shown that mathematics curricula, overall, in the United States is repetitive across grade levels (National Mathematics Advisory Panel [NMAP], 2008; Schmidt et al., 2005; Schmidt, Houang, & Cogan, 2002), leaving little room for comprehensive study of a particular topic (Burrill, 1998). Furthermore, repetition year after year of the same material without significantly increasing complexity does not allow for the integration and development of more complex mathematical thinking. Additionally, there is evidence to suggest that the majority of time in US mathematics classes is spent on routine procedures and practice rather than on problem solving (Burrill; Stigler & Hiebert, 1998). Without problem solving, it is difficult to transition to higher forms of mathematical thinking.

Mathematics Education Reform

To address concerns related to mathematics performance, as well as criticisms of curriculum and instruction, there have been efforts to reform mathematics education in the United States. For example, in order to foster more complex mathematical thinking (Gray et al., 1999), it has been noted that an overall structure of mathematics education must move past particular

elements and into a more coherent understanding of mathematics as a whole discipline (Schmidt et al., 2005). To promote this more coherent view of mathematics, the NCTM has developed a comprehensive set of *Principles and Standards for School Mathematics* (NCTM, 2000), including both content and process standards. The five content standards include the categories of number and operations, algebra, geometry, measurement, and data analysis and probability. The process standards help to create greater cohesion within the mathematics curriculum by describing specific mathematical strategies that can be applied across content areas. The process standards are problem solving, reasoning and proof, communication, connections, and representation. Through a coherent curriculum, students have potential to make connections across mathematical topics and apply their knowledge in a variety of settings (NCTM; Schmidt et al., 2002). Even with these reforms in mind, there are questions about whether K-12 schools are preparing students for the rigors of college mathematics. Research related to expectations and readiness will be presented next.

Expectations of Students and Faculty at the College Level in Mathematics

The expectations of college students and faculty in mathematics courses have been investigated by a variety of researchers (e.g., Barnes, Cerrito, & Levi, 2004; LaBerge et al., 1997). Barnes et al. assessed the beliefs and expectations of college students by surveying 1,613 students at the University of Louisville who were taking entry-level general education mathematics courses. The findings indicated that students came unprepared for college mathematics — with suggestions that this was due to low expectations of mathematics performance in K-12 schools. The researchers claimed that this lack of readiness for college mathematics resulted in faculty members at universities inflating grades and lowering their expectations of student performance, thus leading to diminished understanding of mathematical concepts overall. They concluded that in order for students to be ready for college mathematics, higher expectations and better mathematical preparation in K-12 schools are necessary.

Another study (LaBerge et al., 1997) examined expectations for students in college level mathematics courses by interviewing 26 mathematics faculty members among seven different universities in the Midwest. While they found that many mathematics faculty had little awareness of the NCTM Standards (LaBerge et al.), they also found that, for those faculty who were aware of the Standards, there was agreement with the NCTM recommendations. This agreement suggests that the Standards may provide a bridge for connecting high school and college mathematics, and, in turn, learning about college mathematical readiness.

Summary of the Literature

Upon reviewing mathematics achievement in US schools, there are reasons for concern about college mathematical readiness (Martin & Mullis, 2005; NCES, 2006). Research-based reform efforts have called for a coherent curriculum across grades levels and topics in order to promote high-level mathematical performance (Schmidt et al., 2002, 2005). The NCTM Standards (NCTM, 2000) clearly define a set of coherent guidelines related to both content and process involved in building mathematical understanding. Even with NCTM reform efforts, there are concerns that by the time students reach the collegiate level of mathematics, skills such as proving concepts and thinking mathematically at a complex level are lacking (Goranson, 1999; Gray et al., 1999; Lutfiyya, 1998). Additionally, the literature has shown that students are not always prepared in terms of workload expectations, high standards of many college mathematics faculties, and skills necessary for complex mathematical thinking (Barnes et al., 2004; Berry, 2003; Gray et al.). Further understanding of connections between K-12 and college mathematics may assist mathematics educators with future recommendations.

By surveying a sample of college and university faculty members within public universities and colleges in a northeastern state in the United States, this research sheds light on the question of mathematical readiness for entering freshmen. The results provide indications as to the skills that students should possess at the college level in order to construct knowledge at an advanced mathematical level. This may help to inform both K-12 and college-level mathematics educators in order to better prepare their students.

Methodology

A questionnaire was developed, administered, and analyzed in order to investigate college mathematics instructors' perceptions of mathematical readiness of the average incoming freshmen, as well as their opinions on the importance of mathematical topics and skills related to success in college-level mathematics

(see Appendix for full questionnaire). The interpretation of the average freshmen could vary according to the faculty member; as a result, only perceptions of faculty members were measured.

Developing the Instrument

The instrument was developed following recommendations of Gable and Wolf (2001). Initial constructs were based on the NCTM (2000) *Principles and Standards* and were further informed by other research and professional literature, as well as input from mathematics education experts. A content-validity questionnaire was developed and administered to mathematics education experts. This questionnaire asked the experts to rate the importance of the constructs and the classification of each item according to the specified constructs. Additionally, the experts were asked to rate the certainty of their classification choice and the relevancy to the overall question of college mathematical readiness. Finally, open-ended questions were added to obtain further feedback from the reviewers.

After reviewing the results of the content validity questionnaires, a final instrument was developed (see Appendix). The instrument included six demographic questions, 30 scaled items, and three free response questions. The scaled items related to specific mathematical skills and topics. Each item requested two different scaled responses: the first scale asked for perceptions of skill of average incoming freshmen using a 0-5 scale (0 = never; 1 = very poor; 2 = poor; 3 = adequate; 4 = proficient; 5 = excellent); the second scale asked for opinions of the importance of the skill or topic for college mathematics using a 0-2 scale (0 = not important; 1 = somewhat important; 2 = very important). In addition to the scaled items, three free response questions provided opportunities for participants to add their own experiences with students' mathematical abilities, as well as additional skills and topics they deemed important.

The 30 scaled items included four main constructs: subject knowledge, measurement and data representation, number sense, and mathematical reasoning and generalization. Within the subject knowledge construct, there were three subconstructs: algebra, geometry, and calculus, trigonometry, and probability (items related specifically to statistics were not included because some of the institutions separated mathematics and statistics faculty). The items within the subject knowledge construct were based on expected learning outcomes for high school students as noted in the NCTM (2000) *Principles and Standards* and the state curriculum frameworks.

Data Collection

The survey was administered electronically, complying with institutional review board policies. The participants in this study comprised 22 mathematics instructors representing eight different public colleges and universities in a northeastern state in the United States, of which five institutions awarded four-year degrees and three awarded a small number of four-year degrees but primarily were two-year institutions. Specifically, the 22 participants included 7 professors, 5 associate professors, 2 assistant professors, 7 adjunct professors, and 1 lecturer; 15 were male and 7 were female. Years of experiencing teaching mathematics at the college or university level ranged from 2 to 42 years. The participants reported that they taught from 30 to 250 freshmen in a given year in two to nine different courses each.

Analysis of the Data

Scaled items. Analysis of the scaled items was performed using SPSS software and standard statistical techniques (Green, Salkind, & Akey, 2000), including finding means, standard deviations, skewness, and tests for normality. Given the relatively small sample comprised in this study, it was decided to focus primarily on means and standard deviations in the analysis. Although the sample size was not sufficient for performing a factor analysis (Grimm & Yarnold, 1998), the four constructs identified during the content-validity process were revisited during the analysis process. Means and standard deviations were found not only for each item, but also for the four constructs (i.e., subject knowledge, number sense, measurement and data, and reasoning and generalization).

Free response item analysis. The free responses were coded selectively (Strauss & Corbin, 1990) according to the original constructs. Additionally, open and axial coding were used to identify themes not represented by the original constructs. After the items were classified, peer debriefing (Lincoln & Guba, 1985) was employed to validate the classification and coding of the qualitative data. If there were disagreements in coding, they were discussed until consensus was achieved. Along with calculating frequencies, the coded responses were inspected for patterns and themes that might further elucidate the perceptions of college mathematics instructors related to mathematical readiness.

Results and Discussion

Results and discussion will focus first on overall subject knowledge and then on specific subject areas. Since algebraic subject knowledge represented a high frequency of the responses within open-ended questions and also comprised a relatively large number of the scaled items, it will be reported and discussed in greater depth than the other subject areas. The questionnaire asked the participants to respond based on their observations of the "average incoming freshman" in their mathematics classes; therefore, results cannot be parsed according to specific classes, nor can they be generalized to represent all freshman students.

Subject Knowledge

Overall results of scaled items. When asked to rate the mathematical *ability of an average freshman*, the mean rating was 2.17 (*SD* 1.0316) across all items within the subject knowledge construct. On the 0-5 scale, this falls between the poor and average rating. When asked to rate the *importance* of topics within the subject knowledge construct, the mean rating was 1.516 (*SD* 0.666). On the 0-2 scale, this falls between somewhat important and very important. This demonstrates a potential disconnect between perceived mathematical ability (i.e., poor to average) and importance of mathematical topics (i.e., important).

Overall results of free response items. Participants mentioned topics related to subject knowledge in all three of the free response items. The first question asked, "Are freshman prepared for the mathematics requirements at your school?" Of the 22 respondents, only 2 (9.1%) said that freshman were prepared, and even these qualified their responses with statements such as, "generally"; 13 (59.1%) said that freshman were not prepared; another 4 (18.1%) said that some were prepared and some were not; 2 (9.1%) of the respondents did not answer this question. Within their responses to this question, participants mentioned a topic related to subject knowledge in 9 of the 22 responses (40.9%). Within that number, 8 made additional comments mentioning subject knowledge skills that were lacking. The second question asked, "What are some mathematical skills and topics that students are lacking when entering college?" Participants mentioned subject knowledge topics in 13 of 22 responses (59.1%). Of the 13 responses, 10 mentioned algebraic knowledge, with the remaining responses falling within geometry, statistics, and overall basic skills. The last free response item asked, "What are some of the strong mathematical skills that entering college freshmen have?" Again, 13 of 22 responses (59.1%) mentioned a topic in the subject knowledge construct. Across the three questions, the clear majority of responses related to subject knowledge.

Given results of both the scaled and free response items, it seemed clear that subject knowledge was perceived as important. To further uncover the perceptions of these faculty members, results from the analysis of subconstructs will be reported. As noted previously, results will focus primarily on those related to algebra — since it is the subject topic that stood out in the responses. Following this, results related to geometry, and then those related to calculus, trigonometry, and probability will be discussed. Next, results associated with reasoning and generalization and number sense will be described. Finally, the constructs of measurement and data, as well as the additional findings obtained through open and axial coding, will be reported.

Algebra

Scaled response results. Within the 30 scaled response items, 6 related to algebra. Four of the items obtained a mean score within the poor range; 2 items fell within the very poor range (see Table 1 for means and standard deviations). Of these data, the highest mean of 2.9 (*SD* 0.852) in the entire subject knowledge construct occurred with the first item related to solving algebraic equations in one variable; this is between the poor and adequate range. The next highest rating within the algebra category related to the ability to graph functions (Mean: 2.86, *SD* 0.854) and ability to combine algebraic expressions (Mean: 2.76, *SD* 0.889). The faculty rated the importance of these two topics with means of 1.77 (*SD* 0.429) and 1.91 (*SD* 0.294), respectively. This shows that while these topics were rated within the very important range, related student ability was perceived within the poor to adequate range. Of the scaled ability level responses within algebra, the two lowest were finding the inverse for invertible expressions and solving algebraic expressions in two variables. Both fell between the very poor and poor ability levels, with the perceived importance rated as somewhat important to very important.

Free response results. The free response items helped to underscore the scaled response results. In responding to the question, "Are freshmen prepared for the mathematics requirements at your school?", many participants observed insufficient algebra manipulation and insight. In addition, the participants remarked that

Table 1
Means and Standard Deviations for Subject Knowledge — Algebra

Mathematical construct	Perceived student skill[a]		Perceived importance[b]	
	Mean	*SD*	Mean	*SD*
Item 1 — Students are able to solve algebraic functions in one variable.	2.90	0.852	1.90	0.301
Item 3 — Students use algebra to solve mathematical word problems.	2.00	0.707	1.95	0.218
Item 11 — Students are able to combine given algebraic expressions.	2.76	0.889	1.91	0.294
Item 12 — Students are able to graph different functions.	2.86	0.854	1.77	0.429
Item 13 — Students are able to find the inverse for given invertible expressions.	1.84	1.068	1.33	0.730
Item 21 — Students are able to solve algebraic equations in two variables.	1.89	0.875	1.75	0.444

[a] Skill measured on a 0-5 scale: 0 = never; 1 = very poor; 2 = poor; 3 = adequate; 4 = proficient; 5 = excellent
[b] Importance measured on a 0-2 scale: 0 = not important; 1 = somewhat important; 2 = very important.

the lack of readiness resulted in students taking remedial mathematics courses in college in order to learn material that they thought should have been covered in high school. For example, one participant observed that "51% [of entering freshmen] had to take remedial math because of low SAT scores and failing the placement test." Another participant said, "Roughly 85% of incoming freshmen place into a remedial math class." Yet another participant shared, "Too many need to retake second, and even first, year high school algebra. Those who don't need those remedial classes are typically just adequate in algebra skills except incoming math and science majors." These responses indicate that these faculty members perceive that the average incoming freshmen do not enter with the proper algebraic skills to complete the required mathematics courses at the participating institutions.

Participants offered opinions about relationships between high school coursework and mathematical readiness. For example, one participant said, "Those who took 4 years of math in high school and who took rigorous courses are well prepared. Others who did not take a senior math or did not go beyond geomctry are not well prepared." Another participant conjectured that even with four years of high school math, many students may be unprepared for college math, suggesting that they may be rushed through algebra, trigonometry, and geometry in order to get to calculus. Overall, responses seemed to support the literature recommending that students in high school should take four years of mathematics (Schmidt et al., 2005), but with some caution that students not be rushed through key courses and concepts that could ground their mathematical understanding. Specific skills and topics that may be important for this grounding will be described next.

The second free response question, "What are some mathematical skills and topics that students are lacking when entering college?", elicited an overwhelming majority of responses dealing with algebra. A total of 10 out of the 13 responses (77.0%) within the subject knowledge construct dealt with algebraic topics. Five participants mentioned general algebraic skills or algebraic manipulations as a major weakness of average incoming freshmen. Specific skills that were mentioned included manipulating inequalities, understanding where algebraic formulas come from, the quadratic equation and applications, the distributive power over addition, function notation, and exponents. Although many of these concepts are ones included in high school algebra courses, they are clearly perceived as weaknesses of average college freshmen.

The final free response question asked, "What are some of the strong mathematical skills that entering

college freshmen have?". The majority of responses, 10 out of 13 (76.9%), included algebraic skills. However, the skills seen as strengths were of much lower level than those noted as lacking. For example, strong skills included the following: a mild ability to manipulate algebraic expressions, basic algebra skills, memorizing formulas without understanding, the slope-intercept form of linear equations, memorizing the quadratic formula but being unable to use it, plotting points, the Pythagorean theorem; solving linear equations in one variable, and the ability to solve some quadratic equations but inability to solve in unfamiliar contexts. Two responses stated that students who placed out of remedial college courses were competent in algebraic manipulations. Looking across responses, a majority of the stronger skills identified (61.5%) related to very basic-level algebra. This shows that across the free response items, the faculty perceived that average students were prepared for some topics in basic algebra courses, but were weaker with topics in intermediate algebra. There appears to be a discrepancy between perceived algebra skills and expectations for readiness to engage in college mathematics.

Geometry

Scaled response results. Three of the 30 scaled response items related to geometry, specifically, analyzing two-dimensional and three-dimensional objects and the topic of similarity (see Table 2). Mean skill levels were found to be poor to adequate for finding the area of two-dimensional objects and from very poor to poor for three-dimensional analysis. According to national and state standards, area of two-dimensional objects should be mastered by middle school, and three-dimensional properties should be covered in high school (Goranson, 1999; NCTM, 2000); yet, faculty are reporting poor performance for these at the beginning of college. Responses related to similarity revealed perceptions that students have poor to adequate abilities; yet these skills were ranked as important.

Free response results. The following weaknesses were noted by one or more of the respondents: general geometry, and, specifically, in finding perimeter, area, and volume of objects. Strengths noted included converting angles from radians to degrees, finding the area of triangles and circles, and basic geometry. These results are consistent with those of the scaled items in that greater strengths were noted in procedural skills and greater weaknesses were noted in more conceptual skills, especially those related to analyzing three-dimensional objects. There were some inconsistencies with responses for geometry, including finding areas of triangles and the general concepts within the discipline of geometry. This may be due to the fact that average freshmen do not take college level geometry classes. This should be explored in future studies.

Trigonometry, Probability, and Calculus

Scaled response results. Overall, trigonometry, probability, and calculus were seen as less important than algebra and two-dimensional geometry (see Table 3). Understanding trigonometric relationships was the lowest-ranked skill within the subconstruct and the third lowest-ranked overall among all subject knowledge items. However, this skill was not seen as

Table 2
Means and Standard Deviations for Subject Knowledge — Geometry

Mathematical construct	Perceived student skill[a]		Perceived importance[b]	
	Mean	*SD*	Mean	*SD*
Item 15 — Students can determine similarity between two objects based on their properties.	2.59	1.004	1.47	.513
Item 20 — Students can calculate the area of a two-dimensional object within the standards of Euclidean geometry.	2.53	1.073	1.67	.483
Item 30 — Students are able to analyze properties of three-dimensional objects.	1.53	1.007	1.21	.787

[a] Skill measured on a 0-5 scale: 0 = never; 1 = very poor; 2 = poor; 3 = adequate; 4 = proficient; 5 = excellent
[b] Importance measured on a 0-2 scale: 0 = not important; 1 = somewhat important; 2 = very important.

Table 3
Means and Standard Deviations for Subject Knowledge — Calculus, Trigonometry, and Probability

Mathematical construct	Perceived student skill[a]		Perceived importance[b]	
	Mean	*SD*	Mean	*SD*
Item 2 — Students can use trig relations to determine angle measure of n-gons.	1.67	0.767	.67	0.796
Item 4 — Students can calculate the probability of both dependent and independent events.	1.53	0.964	1.05	0.590
Item 10 — Students understand the concept of a limit.	1.68	0.885	1.38	0.669

[a] Skill measured on a 0-5 scale: 0 = never; 1 = very poor; 2 = poor; 3 = adequate; 4 = proficient; 5 = excellent
[b] Importance measured on a 0-2 scale: 0 = not important; 1 = somewhat important; 2 = very important.

important, as other skills across subjects (mean importance 0.67). Similarly, both the skill and importance levels for finding the probability of dependent and independent events were among the lowest for subject knowledge. In contrast, while understanding the concept of a limit ranked in the bottom four for skill level, it was ranked as relatively important (mean importance 1.38).

Free response results. The free response data included only a few responses for trigonometry, probability, and statistics. When asked if students were ready for college mathematics, one participant conjectured that trigonometry was rushed in order for students to get to calculus. One participant observed descriptive statistics as a weak skill for students; another participant observed trigonometry as a strong skill for the average incoming freshman.

Reasoning and Generalization

Scaled response results. Within this construct, the mean response for student ability was a 1.717 (*SD* 0.944), with an importance rating of 1.743 (*SD* 0.5136) (see Table 4). These scores represented the lowest mean ability paired with the highest mean importance. This indicates that while these college mathematics faculty members view reasoning and generalization as the most important skill for incoming college freshmen, average students' abilities with this skill were perceived among the lowest. In fact, this construct produced the only unanimous response among the faculty members, with faculty giving a mean rating of 2.00 (*SD* 0.00) when asked the importance for students to be able to problem solve. Students were rated as having a mean score of 2.19 (*SD* 0.873) for this skill, ranking between the very poor and poor ratings. Even more telling was that seven out of the nine skills for reasoning and generalization scored within the very poor to poor range for student ability — the ability to find connections between ideas, reflect on their own reasoning, prove a given conjecture, apply a given method for solving problems in multiple contexts, develop their own conjectures, use various forms of reasoning to problem solve, and develop some form of proof given a theorem.

Free response results. The free response items concur with the scaled response data. Thirteen out of 22 responses (59.1%) named reasoning and generalization as a weakness; three participants (13.6%) named student reasoning and ability to solve word problems as major weaknesses. The same number of participants reported that students could not think about mathematics beyond memorization of facts and procedures. For example, a participant noted that students do not have an "[a]wareness that one can understand math at a level beyond rote formulas." This suggests that the participants perceive that average incoming freshmen at their institutions are not living up to the expectations set by NCTM and the international community (Martin & Mullis, 2005; NCTM, 2000).

Three participants mentioned the inability of students to make connections between mathematical ideas and apply concepts to a variety of situations. For example, one participant noted the "[i]nability to make connections between different mathematical representations (for example, solving f(x) = 0 but not realizing that this gives the x-intercepts of the graph of f(x))." Inability to make these connections is of concern, since connecting and applying mathematical ideas have been identified as necessary for building

Table 4
Means and Standard Deviations for Reasoning and Generalizations

Mathematical construct	Perceived student skill[a]		Perceived importance[b]	
	Mean	*SD*	Mean	*SD*
Item 7 — Students are able to problem solve.	2.19	0.873	2.00	0.000
Item 8 — Students can find connections between mathematical ideas.	1.81	0.680	1.95	0.213
Item 14 — Students can reflect on their own mathematical reasoning.	1.67	0.966	1.95	0.213
Item 16 — Students can prove a given conjecture.	1.10	0.852	1.33	0.658
Item 17 — Students are able to justify the answers to their solutions.	2.10	0.889	1.95	0.213
Item 19 — Students are able to apply a given method for solving problems in multiple contexts.	1.95	0.973	1.82	0.395
Item 22 — Students can develop their own conjectures.	1.58	1.071	1.52	0.680
Item 24 — Students can use various forms of reasoning to problem solve.	1.95	0.759	1.91	0.294
Item 28 — Students can develop some form of mathematical proof for a given theorem.	1.05	0.826	1.19	0.680

[a] Skill measured on a 0-5 scale: 0 = never; 1 = very poor; 2 = poor; 3 = adequate; 4 = proficient; 5 = excellent
[b] Importance measured on a 0-2 scale: 0 = not important; 1 = somewhat important; 2 = very important.

higher level mathematical thinking (Gray et al., 1999). Further weaknesses named by participants included the inability to understand why mathematical procedures and theorems were accurate. For example, responses indicated that students did not understand the concept of a proof or how to use mathematical guesses to reason whether or not an answer makes sense.

Number Sense

Scaled response results. The scaled response data contained five questions related to number sense (see Table 5). The most important result from this construct is that it included the item with the highest ability rating for all 30 items. The mean rating of 3.20 relates to knowing the identity relationship for multiplication and addition. According to the literature, this skill should be covered prior to high school mathematics and does not require higher level mathematical thinking (Goranson, 1999; Gray et al., 1999; NCTM, 2000). The other skills in this construct all fell within the very poor to adequate range, with the pull toward the poor rating. These results indicate that the participants perceive that average incoming students do not have a sense of different number systems or relationships within number systems.

Free response results. The free response items showed additional insights into perceptions of freshmen's understanding of numbers. When asked if average freshmen were prepared for the requirements at the participant's institution, two responses touched upon number sense — specifically the inability for students to perform arithmetic, knowing multiplication tables, and performing calculations with rational numbers. Two participants mentioned the inability to perform basic computation as a weakness. In addition, the inability to use positive and negative numbers, logarithms, and radical exponents were seen as weaknesses.

Consistent with concerns expressed by the recent NMAP report (NMAP, 2008), the inability to use and understand fractions was the most frequently coded topic within number sense. One participant went as far

Table 5
Means and Standard Deviations for Number Sense

Mathematical construct	Perceived student skill[a]		Perceived importance[b]	
	Mean	*SD*	Mean	*SD*
Item 6 — Students know what the identity relationships for multiplication and addition are.	3.20	1.056	1.50	0.598
Item 9 — Students are aware of different number systems including integers, complex numbers, real numbers, imaginary numbers, rational, and irrational numbers.	2.81	1.030	1.59	0.503
Item 23 — Students are able to use properties of integers to justify relationships between whole numbers.	2.05	1.353	1.29	0.644
Item 27 — Students are able to do calculations with complex numbers.	1.65	1.057	1.00	0.725
Item 29 — Students are aware of multiple coordinate systems.	1.42	1.326	0.95	0.759

[a] Skill measured on a 0-5 scale: 0 = never; 1 = very poor; 2 = poor; 3 = adequate; 4 = proficient; 5 = excellent
[b] Importance measured on a 0-2 scale: 0 = not important; 1 = somewhat important; 2 = very important.

Table 6
Means and Standard Deviations for Measurement and Data

Mathematical construct	Perceived student skill[a]		Perceived importance[b]	
	Mean	*SD*	Mean	*SD*
Item 5 — Students are able to use rulers, protractors, or compasses.	3.07	1.163	.77	0.813
Item 18 — Students can successfully represent angle measurements in both radians and degree measures.	2.58	1.346	1.29	0.644
Item 25 — Students can determine the reasonable scale when measuring objects.	2.84	1.068	1.60	0.681
Item 26 — Students can represent given data using correct units.	2.44	0.984	1.70	0.571

[a] Skill measured on a 0-5 scale: 0 = never; 1 = very poor; 2 = poor; 3 = adequate; 4 = proficient; 5 = excellent
[b] Importance measured on a 0-2 scale: 0 = not important; 1 = somewhat important; 2 = very important.

as to say that students were "afraid of fractions." Another participant mentioned the students' inability to manipulate and simplify fractional expressions. Only one participant mentioned number sense as a strength — namely knowing odd and even numbers, positive and negative numbers, and understanding the comparison of sizes between numbers. These skills are ones that should be mastered prior to high school algebra or covered within the beginning of an elementary algebra course (NCTM, 2000).

Measurement and Data

Scaled response results. This construct focused on skills in measuring and correctly representing data, as opposed to statistical analysis (see Table 6). The item of interest was the ability to use rulers, protractors, or compasses. While the ability level fell within the adequate range, the importance level fell within the not important to somewhat important range. This was the second highest ability rating overall, but the second lowest importance rating of all responses.

Free response results. Responses coded for this construct were found related only to the skills that were lacking — for example, inability to extract relevant information from word problems or determine reasonableness of their answer, and inability to visualize and manipulate data to solve problems. The results indicated that physically measuring objects was not deemed important for college-level mathematics; however, representing data and using correct scales and units were seen as somewhat important to important by most faculty members.

Calculators and Study Skills: Additional Constructs

Open and axial coding of the free response items revealed two new constructs — the use of calculators by students and student study skills. The calculator construct will be defined as using graphing calculators or similar devices to graph and/or compute numbers. Most responses indicate that the participants perceived an overreliance on the calculator by incoming college freshmen, suggesting that students are not forming a true understanding of the calculations they are performing. One participant, however, stated that students knew how to use graphing calculators for computational means and to better understand and visualize problem sets.

The study skills construct will be defined as the students' method of studying or practicing mathematics. Study skills made up 3 out of 22 responses (13.6%) related to skills that were lacking. One participant shared that students were not able to learn independently, had insufficient study skills, did not have enough inquisitiveness into the discipline of mathematics, or had the patience to give the time and effort required to learning the material.

Conclusion and Implications

This study uncovered the perceptions of public university and college mathematics faculty members of the importance of specific mathematics topics and of average freshmen's abilities associated with these topics. While the results cannot be generalized to all incoming freshmen, the perceptions of these mathematics instructors related to *average freshmen* provide insight about potential strengths and areas of improvement that may be worthy of closer scrutiny by high school mathematics educators, college mathematics faculty, and mathematics education researchers. In particular, this study demonstrated that mathematical topics considered important for entering college students were often associated with perceptions of inadequate skills. Indeed, all four original constructs (i.e., subject knowledge, number sense, measurement and data, and reasoning and generalization) were rated between somewhat important to important (see Table 7), yet most skills were rated low. Major findings of this study will be summarized, leading into implications and recommendations, and, finally suggestions for future research.

A major finding of this research is that the ratings for student skills, overwhelming, show that the mathematics faculty perceived that *average freshman students* are not ready for college mathematics. Every mean score for student skill, across all contents, fell either within the very poor or the poor range. To further underscore this idea, of all the responses ranking student skills on a scale of 1-5 (with 5 as an excellent rating), only two participants used the rating of 5. In addition, only 4 of the 30 skills represented on the survey received a rating of 5. By identifying

Table 7
Means and Standard Deviations for Overall Constructs

Mathematical construct	Perceived student skill[a]		Perceived importance[b]	
	Mean	*SD*	Mean	*SD*
Subject knowledge	2.17	1.032	1.52	0.666
Number sense	2.26	1.340	1.28	0.686
Measurement and data	2.72	1.149	1.33	0.767
Reasoning and generalization	1.72	0.944	1.743	0.514

[a] Skill measured on a 0-5 scale: 0 = never; 1 = very poor; 2 = poor; 3 = adequate; 4 = proficient; 5 = excellent
[b] Importance measured on a 0-2 scale: 0 = not important; 1 = somewhat important; 2 = very important.

constructs and topics that were ranked simultaneously with high importance and low skills, implications and recommendations for precollege mathematics are suggested. For example, the analysis uncovers specific skills and concepts worth considering, as high school educators create and modify mathematics curricula with an eye toward helping their students to be successful in college. Topics and concepts that stood out among the results will be highlighted.

Reasoning and generalization was considered the most important construct for entering freshman and was also ranked the lowest in terms of perceived student competency. This finding is compatible with research that suggests that poor performance of US students in international comparisons (Martin & Mullis, 2005) may relate to an emphasis on routine procedures rather than on reasoning and generalization in mathematics classes (Schmidt et al., 2002, 2005). This research supports reform initiatives that suggest that reasoning and generalization should be stressed during high school years — for example, by shifting away from simple procedures and practice toward instruction that incorporates tasks that allow students to find connections among mathematical ideas, reflect on their reasoning, justify their answers, develop their own conjectures, and use various forms of reasoning to solve a problem (Lutfiyya, 1998; NCTM, 2000). These changes could encourage stronger mathematical thinkers whose competencies would more closely match the expectations of college mathematics faculty.

There were particular topics within the subject knowledge construct that were noted as being both highly important and in need of improvement. Algebraic subject knowledge (e.g., combining algebraic expressions and graphing functions) stood out in this regard. An emphasis on algebraic reasoning is aligned with initiatives that identify algebra as a critical gateway to higher mathematics (NMAP, 2008). Other key areas identified include geometry (e.g., analyzing 2D and 3D objects) and number sense (e.g., basic math procedures and ability to use and understand fractions). These findings suggest that precollege mathematics should include emphases on algebraic reasoning, geometry, and number sense.

Along with emphases on particular content areas, additional curriculum and instruction recommendations were uncovered by this study. For example, consistent with research literature (Schmidt et al., 2005), the study suggests that requiring a fourth year of mathematics during high school would strengthen student competencies and college mathematical readiness. Additionally, although the NCTM (2000) Standards emphasize K-12 mathematics education, the college faculty surveyed rated NCTM recommended skills and concepts as important. This provides credence that the NCTM standards can serve as a useful model when creating curricula to meet recommendations for K-12 education and also *to meet expectations of college mathematics faculty*. Along with supporting previous research and recommendations for K-12 mathematics education, this study furthers current knowledge by *explicitly connecting these ideas to readiness for college mathematics* and by *more clearly articulating topics and competencies that could benefit from additional emphasis during high school*.

While the relatively small sample size and the nature of the investigation limits generalizability, the research, especially when combined with literature, suggests that there is a perceived lack of student preparedness for college mathematics — a concern that needs to be addressed. In order to further understand the important issue of mathematical readiness for college students, follow-up research is suggested. First, a larger sample size across more institutions would help to confirm the results of this research. Second, developing a survey that more clearly defines "average freshman" and/or that parses out freshmen according to levels of mathematics classes in which they are enrolled may provide additional insight into perceptions of readiness. Third, investigating perceptions of high school mathematics educators along similar lines (i.e., ranking importance and competency) would allow for a broader view of the issues involved. This study provides a foundation for these future investigations.

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Author's Note

The research reported in this article is based on the first author's honors thesis at the University of Connecticut under the direction of the second author.

Appendix

Mathematical Readiness Survey

This survey is designed to provide information on college faculty's perspectives on the readiness of college freshmen throughout the state in which you teach. The survey will also display information on the importance of different topics for students to have mastered before entering college. It is important that your answers reflect actual observations of the average student in your mathematics classes.

Upon completion of the survey, please email this form as an attachment. Remember to delete the email from your sent box to secure your anonymous responses. Also, the attached form will be saved to a hard disk immediately after it is received and the original email will be deleted.

The definition of college mathematical readiness is the degree to which a student is predicted to succeed in the college environment in mathematics.

Faculty Information:

Please answer the following with the appropriate information.

1. Gender:
2. Years of teaching at collegiate level:
3. Position Title (Examples include professor, TA, etc.):
4. Approximate number of students you teach in a given school year:
5. Approximate number of freshmen you teach in a given year:
6. Classes that you teach that include at least one freshman:

Please use the following response scale to answer the following questions. The scale to the left will represent your responses to the ability of the average incoming freshman. The scale to the right will indicate your opinion of the importance of the skill or topic for college mathematics. Please type your answer in each box

Response Scale (Left Side)	**Response Scale (Right Side)**
0 — Never	0 — Not important
1 — Very Poor	1 — Somewhat important
2 — Poor	2 — Very Important
3 — Adequate	
4 — Proficient	
5 — Excellent	

Ability of average freshman		Importance of topic
	1. Students are able to solve algebraic functions in one variable.	
	2. Students can use trig relations to determine angle measure of n-gons.	
	3. Students use algebra to solve mathematical word problems.	
	4. Students can calculate the probability of both dependent and independent events.	
	5. Students are able to use rulers, protractors, or compasses.	
	6. Students know what the identity relationships for multiplication and addition are.	
	7. Students are able to problem solve.	
	8. Students can find connections between mathematical ideas.	

9. Students are aware of different number systems including integers, complex numbers, real numbers, imaginary numbers, rational, and irrational numbers.
10. Students understand the concept of a limit.
11. Students are able to combine given algebraic expressions.
12. Students are able to graph different functions.
13. Students are able to find the inverse for given invertible expressions.
14. Students can reflect on their own mathematical reasoning.
15. Students can determine similarity between two objects based on their properties.
16. Students can prove a given conjecture.
17. Students are able to justify the answers to their solutions.
18. Students can successfully represent angle measurements in both radians and degree measures
19. Students are able to apply a given method for solving problems in multiple contexts.
20. Students can calculate the area of a two-dimensional object within the standards of Euclidean geometry.
21. Students are able to solve algebraic equations in two variables.
22. Students can develop their own conjectures.
23. Students are able to use properties of integers to justify relationships between whole numbers.
24. Students can use various forms of reasoning to problem solve.
25. Students can determine the reasonable scale when measuring objects.
26. Students can represent given data using correct units.
27. Students are able to do calculations with complex numbers.
28. Students can develop some form of mathematical proof for a given theorem.
29. Students are aware of multiple coordinate systems.
30. Students are able to analyze properties of three-dimensional objects.

Please provide brief comments on the following questions:

1. Are freshmen prepared for the mathematics requirements at your school?

2. What are some mathematical skills and topics that students are lacking when entering college?

3. What are some of the strong mathematical skills that entering college freshmen have?

The Impact on Incorporating Collaborative Concept Mapping with Coteaching Techniques in Elementary Science Classes

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The purpose of this research was to evaluate a collaborative concept-mapping technique that was integrated into coteaching in fourth-grade science classes in order to examine students' performance and attitudes toward the experimental teaching method. There are two fourth-grade science teachers and four classes with a total of 114 students involved in the study. This study used a mixed method design, incorporating both quantitative and qualitative techniques. The findings showed that the two teaching methods obtained significant difference with respect to students' test scores. Using collaborative concept mapping to learn science could increase the opportunity of discussion between peers, thus fostering better organization and understanding the content. In addition, coteaching could enable teachers to share their expertise with one another. It could facilitate the implementation of collaborative concept mapping and the construction of student's concept mapping. Team teachers' attitude could affect the students' learning performance. However, some of the students had negative views on drawing concept maps because they found it was troublesome to write down many words, difficult to draw and arrange proposition, and time-consuming. Coteachers' instant feedback and students' journal writing could guide and examine the students' concept maps to facilitate their cognitive learning.

In a society that is undergoing drastic and rapid modifications, education should emphasize the concept of "teach children how to fish rather than give them fishes directly." Under our current curriculum and teaching reform in Taiwan, one of our educational goals is to foster students' ability to apply their existing knowledge to new fields (Ministry of Education, 2001). Concept mapping applies the idea of drawing concepts to represent the knowledge structure about the subject matter (Mintzes, Wandersee, & Novak, 1997; Novak & Gowin, 1984). When creating concept maps, learners need to integrate the relationships between each of the concepts. When organizing concepts, learners will have more opportunities to self-evaluate their knowledge structure to see if their concepts on the content area are appropriate, and if their concept mapping is accurate or not. Therefore, concept mapping not only can be a kind of learning tool for "Metacognitive Strategy," but can also help students achieve meaningful learning (Novak, 2002). Hence, concept mapping is a tool to help students learn how to learn (McClure, Sonak, & Suen, 1999; Ruiz-Primo & Shavelson, 1996). It has also been proved that the use of evidence mapping is superior to prose writing (Toth, Suthers, & Lesgold, 2002). It provides students chances to organize their learning. In the processes of creating concept maps, students are able to see what they have learned and what they have not learned. Through this self-evaluation process, students would develop better metacognitive skills.

Since concept mapping is a new learning tool for current elementary students in Taiwan, it is hard for them to start individually. Therefore, adopting the method of collaborative study not only can eliminate the pressure on students, but can also benefit students by gathering opinions from various sources. Many studies have also documented that students become more active learners, upon interacting with teachers or peers within a collaborative learning environment (Briscoe & Prayaga, 2004; Gijlers & de Jong, 2005; Keys, 1996; Palincsar, Anderson, & David, 1993). The issue of how scientific knowledge is constructed in some way sheds light on how knowledge is negotiated or co-constructed in social settings. Co-construction refers to the process of jointly building an understanding, as would be characterized by collaborative learning experiences (Kittleson & Southerland, 2004). Collaborative concept mapping can help students with lower achievement to understand the subject and build the connection with their existing knowledge (Guastello, Beasley, & Sinatra, 2000). Okebukola (1992) thought that by doing concept mapping under a cooperative learning situation, the learning environment kindles the improvement of students in their cognitive and emotional learning. Moreover, collaborative concept mapping acts like a puzzle. Everyone can

contribute one piece of information to the puzzle to make it more complete (Brown, 2003). Hence, the training in collaborative concept mapping is very helpful to students for reinforcing their learning achievement, interest and subject understanding. This is worth more in-depth exploration by educators.

The teachers who use collaborative concept mapping need rich professional knowledge and skills. However, since every teacher is not capable of doing that, the method of instruction must rely on team collaboration to overcome the difficulty. The related tendency of collaborative teaching among teachers is coteaching. Collaboration is also identified as a key aspect in the professional growth of teachers. An effective professional growth must be collaborative, involving a sharing of knowledge among teachers' communities of practice rather than depending on individual teachers (Darling-Hammond & McLaughlin, 1995; Firestone & Rosenblum, 1998; Roth, Tobin, Zimmermann, Bryant, & Davis, 2002). Coteaching deals with collegiality and professional sharing. Researchers report that regular opportunities for interaction with colleagues are essential in creating professional school cultures (Lieberman, Saxl, & Miles, 1988; Miller, 1988). A community of peers is important not only in terms of support, but also as a crucial source of ideas and criticism (Sykes, 1996). Coteaching provides regular and frequent opportunities for individual and collegial reflection in classrooms and other institutional practices (Jang, 2006a; National Research Council, 1996).

Several studies have pointed out that collaborative concept-mapping techniques are interpreted as the representation of students' knowledge structures, which might provide the possible means of promoting relational conceptual change and understanding (Liu, 2004; Novak, 1998; Roth & Roychoudhury, 1993; Wellington & Osborne, 2001; Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005). Research has also shown that coteaching is an effective way of constructing deep learning of concepts (Roth et al., 2002; Tobin, Roth, & Zimmermann, 2001) and enhancing students' achievement (Jang, 2006a, 2006b) while acquiring alternative ways to teach the same subject matter. However, there has been less research into the means of integrating collaborative concept-mapping techniques with coteaching in elementary science education. This research evaluates a collaborative concept-mapping technique environment that was integrated into coteaching in fourth-grade science classes. The research questions of this specific research were as follows:

1. What was the students' performance toward the experimental teaching method?
2. What were the students' attitudes toward the experimental teaching method?
3. How did the co-teaching technique affect students' concept learning and performance?

Rationale

This section first describes the related literature concerning social constructivism for knowledge construction through both collaborative concept-mapping and coteaching techniques, and then addresses merits of collaborative concept-mapping and empirical studies. Finally, coteaching is presented and its forms and strengths are described.

Social constructivism. Several researchers in science education would recognize that knowledge is socially constructed (Alexopoulou & Driver, 1996; Jang, 2006a, 2007; Kelly & Crawford, 1997; Richmond & Striley, 1996). For many of these researchers, the role of discourse in shaping what is viewed as legitimate understanding within a scientific community becomes a paramount factor in the construction of knowledge. Social constructivists emphasize that the notion of intersubjectivity is very important (Rogoff, 1990). It allows for joint thinking, problem-solving, and decision-making processes from which the learner appropriates new knowledge (Newman, Griffin, & Cole, 1989). Not a single person construes the stream of events in the same way as another. As they interact with one another, they develop ideas held in common, and create a universe of discourse, and a common frame of reference in which communication can take place (Solomon, 1987). Knowledge is collaboratively constructed between individuals from where it can be appropriated by each individual (Vygotsky, 1978). In this study, social constructivism gives students and team teachers the opportunities to act on their ideas and reflect upon their actions. For students, utilizing collaborative concept mapping fosters their understanding, which evolves through a meaningful negotiation process in which they discuss their own ideas and consider those of others. For teachers, coteaching involves two or more teachers whose primary concern is the sharing of teaching experience in the classroom, and generating cogenerative dialogues with each other for maximizing student learning.

Collaborative concept mapping. The social requirement for concept mapping is to create a collaborative

environment. Students may work in small groups to construct concept maps so that negotiation on relations may take place between partners or among group members. Collaborative concept mapping is a learning process. It can be ongoing during science teaching to promote relational conceptual change and understanding. Conceptual change has to be coordinated with metacognitive changes (Gunstone & Mitchell, 1998). Metacognition refers to the knowledge, awareness, and control of one's own learning path, which are the learning outcomes of science teaching. In order for conceptual change to occur, learners must recognize their conceptions, evaluate these conceptions, decide whether or not to reconstruct the conceptions, and, if they decide to reconstruct, review and restructure other relevant aspects of their understanding in ways that lead to consistency (Liu, 2004). During the process of learning science, students regularly revise their previous concept maps, and are thus fully aware of the changes in their conceptions. The constant revision of concept maps helps students become reflective learners who monitor their understanding and make intentional efforts to improve their conceptual understanding.

Wellington and Osborne (2001) described several structured experiences and tasks to support students' interactions, discussion, and debates. They suggested the use of collaborative concept-mapping activities, and structured critical instances involving common misconceptions, and the use of directed activities related to texts to structure and guide students in small-group activities and discussion. These tasks appear to help structure oral interactions, focus discussion, develop explanations, and promote conceptual understanding. Roth and Roychoudhury (1993) discussed the role of concept mapping from the cooperative learning situation. They thought that collaborative concept mapping can provide students a great environment to communicate with each other by using their common language in a scientific community. The key point is that concept mapping can help students construct their knowledge collaboratively. Liu (2004) also indicated that students were motivated by computerized concept mapping that was intended to promote relational conceptual change. The students viewed concept mapping as helpful for them to see how ideas were connected; they also benefited from interacting with one another during concept mapping. The teacher also valued computerized concept mapping because the student-produced concept maps gave the teacher pertinent information about students' preconceptions and changes to their misconceptions during instruction. The teacher's instructional planning became more efficient and relevant to students' conceptions because of the ongoing process of concept mapping.

Coteaching. On the other hand, coteaching also emphasizes that the notion of intersubjectivity involves two or more teachers whose primary concern is the sharing of teaching experience in the classroom, and cogenerative dialoguing with each other. They take collective responsibility for maximizing learning to teach or becoming better at teaching while providing enhanced opportunities for their students to learn (Tobin et al., 2001). Coteaching provides us with a zone of proximal development, the interaction between individuals and a new form of societal activity. The central purpose of cogenerative dialoguing is to further develop the existing understanding of the teaching situation in order to increase professional growth. Roth et al. (2002) considered coteaching as a good means of achieving deep learning of science concepts while learning alternative ways to teach the same subject matter.

Since coteachers teach together, interactions occur continuously. Coteachers create material and social resources continuously that allow for new forms of agency at subsequent moments. Such resources include physical as well as social spaces and meaning-making entities. Coteachers take advantage of these resources in synchronized and coordinated ways (Roth, Tobin, Carambo, & Dalland, 2005). Jang (2006a) incorporated web-assisted learning with team teaching in seventh-grade science classes. This study used a quasi-experimental method, assigning the four sampled science classes into experimental and control groups. The results showed that the average final exam scores of students experiencing the experimental teaching method were higher than those of students receiving traditional teaching.

There are five different forms of coteaching — one teaching/one assisting, station teaching, parallel teaching, alternative teaching, and team teaching (Cook & Friend, 1996; Friend & Cook, 2003). Even though team teachers adopt different forms of coteaching, it initially undergoes three stages: forming, storming, and norming (Dieker & Murawski, 2003). In the first stage, teachers share their thinking and feelings, create a daily routine, and discuss how they would interact with one another and with the students.

In the second stage, one recognizes that coteaching resembles any other interpersonal relationships in which conflict can occur. Hence, it is crucial that teachers are willing to work through any difficult times and learn from successes and failures. Ultimately, in the third stage, coteachers begin to create their own norms for the classroom as they work in team for the benefit of all students. Therefore, Bennett, Ishler, and O'Loughlin (1992) suggest the following three essential characteristics for good partnerships: a degree of dissimilarity between the partners, the mutual satisfaction of self-interest, and a measure of selflessness on the part of each partner, enough to assure this satisfaction of self-interest.

Research Design and Methodology

This study used a mixed method design, incorporating both quantitative and qualitative techniques. Quantitative analyses were employed to investigate the hypothesized relationships between the teaching methods and student performance. They are discussed with reference to the scores of science tests (the pretest and posttest) to see if there is any significant difference. Qualitative data included a combination of documentary interpretation (Erickson, 1986) and qualitative analysis (Strauss, 1987).

Participants

There are two fourth-grade science teachers and four classes with a total of 114 students involved in the study. The first teacher, Ann, has 10 years of teaching experience. She emphasizes students' responses in class, enjoys learning new knowledge, and is willing to change. She has a strong desire to understand the method of applying concept mapping in teaching and the problems of students' performance. The other teacher, Bee, has five years of teaching experience. She is willing to accept criticism from herself and others to improve her teaching. She is good at teaching with the collaborative learning approach. One of each teacher's two classes was selected to be the experimental group (E1, E2); and the remaining two classes constituted the control group (C1, C2). The numbers of students in each class (E1, E2, C1, and C2) were 28, 30, 29, and 27. In order to prevent gathering students with the same level of achievement, the students were divided according to S-normal distribution. Students at this level were willing to express their own opinions and ask questions toward the teaching contents. Nevertheless, each student's learning background had a huge impact on the learning gap. To make sure that the science grades of the experimental group were consistent with those of the control group before the experiment, the researcher conducted a one-way analysis of variance (ANOVA) of the two groups' science grades taken from the fourth graders' first midterm exam (pretest). The average scores of the four classes — E1, E2, C1 and C2 — were 79.68, 79.12, 80.50, and 80.10, respectively. The one-way ANOVA of mean scores for the four classes ($F = 0.87$, $p > 0.05$) did not show significant difference.

Research Design

The researcher made use of a quasi-experimental method, assigning the four sampled classes to the experimental group (E1 and E2) and the control group (C1 and C2). The experimental group was taught by coteaching using collaborative concept-mapping environment, while the control group received traditional teaching method. Students in the experimental groups were divided into small groups. Students had to do collaborative concept-mapping learning with 4-5 students in each small group. Before the research, the four classes received a pretest, while the posttest scores were the fourth graders' final exam results. From the beginning of the semester, the researcher made sure that coteachers who were going to do the research understood the purpose of this study, the way to implement it, and the resources related to this study.

To develop and to implement coteaching technique, the researcher considered the current teaching practice adopted in Taiwan's classrooms. The researcher did not wish to change the arrangement of classrooms for the teachers who collaborated in the experiment but still hoped to reap the benefits from the coteaching experiment. Therefore, the researcher decided to adopt Cook and Friend's (1996) coteaching model, in which team teachers taught the same subject but different parts in turn. Thus, Ann and Bee cotaught E1 and E2 classes, then Ann taught C1 class and Bee taught C2 class individually. Team teachers needed to meet up together every week in order to discuss the teaching aim and procedures, and to amend shortcomings. After eight weeks of experiment, a survey was conducted, and students in the experimental and control groups were asked for their opinions about the teaching method in the classes.

Procedures of Implementation

The study was conducted for eight weeks during normal class sessions. There were three sessions per week, each session of 40 minutes. Coteachers would work together for planning the syllabus, prepare and

teach, and participate in after-class discussion. In coteaching situation, the class had two teachers in the same classroom, and the two teachers taught different parts of the same subject respectively in a cooperative way. For example, Teacher Bee explained the fundamental concepts of "electric circuit" using concrete objects, whereas Teacher Ann was the teaching assistant responsible for explaining the concepts of "electric circuit" to the students using the concept-mapping technique. Teachers Ann and Bee then coinstructed students on how to operate the experimental activities using collaborative concept-mapping technique. The teaching materials covered the first unit, electric circuit DIY, and the second unit, a beautiful rainbow. The activities included Activity 1: The connection and illumination of a light bulb; Activity 2: The exploration of a battery; Activity 3: Conductive and nonconductive object; Activity 4: A lantern of lantern festival; Activity 5: Let's see rainbow; and Activity 6: A rainbow in the classroom.

Students used concept mapping as their tool of collaborative knowledge construction in the group's collaboration. Students in the group worked together on finding the key concept in every activity. They shared their opinions with each other and discussed the completeness of their concept maps; meanwhile, the teachers evaluated the students' instant feedback and gave each group suggestions about their concept maps. Students integrated concept mapping into their discussion with their peers. Each student was given one "learning journal" 20 minutes before each activity ended. Students could focus their discussion on the content of each individual activity and then draw their concept map regarding each of them. After every group finished their concept map, they would write down feedback on their "learning journal" and present their concept maps to the whole class. The process of presenting concept maps provided an opportunity for the students to share from the learning performances of each other. After the activities, all the students discussed the problems they had encountered during their class and they handed in their journals/assignments for the activities within a certain period of time.

Different from the experimental group, thc control group received the whole class instruction instead. Most of the time, the teaching and learning processes were done by their teacher. Sometimes the teacher might ask students questions to make sure if they understood the topic. Students would do the same activities as suggested in the teaching materials of the experimental group. The assignments were also used for assessment. The control group did not use the collaborative concept-mapping learning technique or "learning journal" writing.

Data Collection and Analysis

The data collected consisted of: (a) scores of the science test which was the fourth-grade students' final exam, the school-wide uniform science test given by the school; (b) responses given in a survey containing multiple-choice questions and open-ended questions that cover the evaluation of the teaching method in order to find out the students' understanding and interests towards the content; (c) student learning journal, the students were asked to first find out the concepts in the content, and discussed with their group members, then draw their concept maps and collaborative concept maps; (d) teacher's handbook written by the science teachers through the overall process of this course; and (e) interviews with students and teachers. A total of 12 experimental students who were involved in the interview performed prior verbal expression. These interview recordings were transcribed verbatim.

Data collected during various stages of the integrated method were analyzed in relation to the three research questions. The first question was answered on the basis of an analysis of scores of the science test, in combination with written student learning journal and interviews. The final science exam consisted of two parts: 20 questions with multiple choice, and 10 questions with fill-in the blanks. The researcher and the two collaborative science teachers took a special effort to evaluate the consistency between the exam questions and teaching units, clarity, and smoothness and appropriateness of the questions. They made the analysis on the difficulty levels of the questions and the distinguishable ability on students' learning results. The analysis showed that the difficulty level was between 0.47 and 0.86, and the distinguishable ability on students' learning was above 0.20. The results indicated its internal consistency and had great reliability based on Cronbach $\alpha = 0.8230$. Moreover, the researcher found that the exam questions had fine content validity and generally met the requiremcnt of the teaching objectives. The exam scores of the students were analyzed statistically using SPSS software after implementing the experimental teaching method. The researcher used ANOVA to discover whether the teaching method has any impact on students' final exam scores (posttest), and whether the difference in

the scores of the students receiving the proposed and traditional teaching methods reach a significant level.

The second question was answered on the basis of an analysis of the survey in combination with the student learning journals and interviews. Each question in the survey had a response scale ranging from "agreement, disagreement, and uncertainty." The investigator calculated the "agreement, disagreement, and uncertainty" numbers of answering the questionnaire transformed the percentage of total students' responses. In addition, there was an open-ended section at the end of each question for the researcher to understand the reason behind the participant's answer. The questions are as follows:

1. I think the teaching method helped my understanding of the content during the class.
2. I think the teaching method helped increasing my interest toward science learning.
3. Overall, I am satisfied with the curriculum of this semester.

The third question was answered on the basis of an analysis of the student learning journals, teacher's handbook, and interviews. The qualitative framework analysis for each research question involved a similar procedure. In order to find the effects of coteaching and collaborative concept-mapping techniques, the investigator developed a coding system by searching through the data for regularities and patterns, and then wrote down words or phrases that represented those regularities and patterns. The process of analyzing the qualitative data consisted of the following three steps: (1) coding and developing temporary coding categories; (2) adopting the constant comparative process; (3) defining categories and producing assertions. First, these words and phrases formed temporary coding categories (Bogdan & Biklen, 1992). Next, the constant comparative method (Strauss, 1987) was adopted for deciding categories; that is to say, every time the new data were collected, the newly collected data were constantly compared with the already existing data. Finally, all data gathered were defined and organized into semantically related categories/assertions.

Results and Discussion

The results were divided into four sections. In the first section, the researcher discussed the effects of experimental teaching on students' final exam performance. In the second section, students' attitudes toward the experimental teaching method were discussed. In the third and four sections, to answer the third question, the researcher explored about the effectiveness of coteaching, and looked at how the attitudes of the team teachers' teaching influenced the teaching outcomes in the research. The following are the summary of the four sections.

The Experimental Teaching Method Enhanced the Students' Performance of Science Learning

Table 1 shows the four classes' descriptive statistics of mean scores and standard deviation of both the pretest and posttests in science. In order to see if the teaching methods are significantly related to the scores of the experimental group and the control group, one-way ANOVA was used to compare the scores of E (n = 58) and C (n = 56). The result indicated a significant difference (F = 4.658, $p < 0.05$). Also, one-way ANOVA was conducted to see if there was a significant difference between teaching methods and the posttest scores of E1 and C1. The findings showed that there was significant difference ($F = 4.453$, $p < 0.05$). Similarly, the posttest scores of E2 and C2 also showed a significant difference ($F = 3.233$, $p < 0.05$). It was observed that incorporating collaborative concept mapping with team teaching did have a positive impact on the final exam scores of the experimental groups.

Although the aforementioned statistics do not reveal the reasons for the increase in students' scores, Table 2 shows that more than half of students (E1:66%; E2:69%) consider that the experimental teaching method can help understand better the content in the class, whereas only less than half of students of C class (C1:46%; C2:43%) did the same views. Some students in the experimental group think that an integrated collaborative concept mapping in science subject teaching could increase the opportunity of discussion between peers in order to foster the

Table 1
Mean and Student Deviation of Pretest and Posttest

Group	Pretest		Posttest	
	Mean	*SD*	Mean	*SD*
E1	79.68	8.82	86.83	8.30
E2	79.12	9.80	83.84	9.41
C1	80.50	8.21	82.45	7.97
C2	80.10	8.91	80.87	8.97

Table 2
The Percentage of Students' Responses in the Questionnaires (%)

Items	Agreement				Disagreement				Uncertainty			
	E1	E2	C1	C2	E1	E2	C1	C2	E1	E2	C1	C2
1. Helped my understanding of the content	66	69	46	43	23	20	33	30	11	11	21	27
2. Helped increasing my interest toward science learning	82	79	51	54	10	13	30	27	8	8	19	19
3. Satisfied with the curriculum	79	76	60	63	10	16	23	26	11	8	17	11

E1 = experimental group 1; E2 = experimental group 2; C1 = control group 1; C2 = control group 2.

organization and understanding of the content. After every group finish their concept mapping, they would have to present their concept mapping to the class. In this case, they can reflect their own concept maps and other students can propose questions according to the presentation. Interaction and negotiation with others allow the learners to adjust personal constructive knowledge, thus advancing the ability of creating a more effective comprehension (Novak, 2002). The following are the opinions drawn from the student interviews and learning journals.

> The strategy of using collaborative concept mapping can help me understand the key concepts better about Rainbow. After I learned the strategy, I can find the main point in the content on my own.

> Collaborative concept mapping can help with organizing the concepts and has great interaction between peers. I would like to continually use this method in the class if there is any opportunity.

> When the students present their concept-mapping activities, I could modify and correct my own concept mapping considering their presentations, which helped me with better understanding of the content in the class.

Regarding coteaching, team teachers could provide their own expertise to complement each other and assist collaborative learning and the construction of concept mapping. Other reasons include, during the teaching process, coteachers would give student guidance whenever necessary. When the student presented concept mapping, coteachers would give them positive encouragement. Students' concept maps would be collected by the coteachers to comment on and given back when they draw concept maps next time in the class. In this case, students can self-correct their concept maps, find their own mistakes, and then accomplish their concept-mapping construction. The following are the responses from the student interviews and learning journals.

> Teacher Ann would collect our concept maps and comment on them, and then gave us back when we draw concept maps next time in the class. In this case, we could self-correct our concept mapping. On the other hand, teacher Bee helped us generate more thinking. We could then know how to cooperate and share ideas to accomplish the concept mapping.

> While we were constructing electric circuit concept maps, co-teachers would walk around the classroom, provide helps when necessary, and give corrections and positive encouragement when we did the presentation.

Students' Attitudes toward the Experimental Teaching Method

Table 2 indicates that a majority of students (E1:82%; E2:79%) think that the experimental teaching has increased the interests of learning science, whereas only half of students of C class (C1:51%; C2:54%) had the same views. Most students feel that the learning with collaborative concept-mapping method is interesting and it is a new experience for them. Furthermore, collaborative learning can motivate the students to participate in the learning process in order to achieve the same goal individually and as a group. By group discussion, they can communicate, explain, and debate on their thinking with peers in public so as to form the process of cognitive

reconstruction and refine knowledge construction. Most of the students, after experiencing the experimental teaching, consider that the teaching method can help understand some concepts and contents better in science learning. During the interaction, the more capable peers can assist the slow learners. The following are students' perspectives toward the teaching methods from interviews and learning journals:

> I feel the experimental teaching is new to me, and is more attractive than the previous teaching method.

> I think that the way of drawing concept map can help me further understand the content of science lessons. Moreover, collaborative learning in the group can also help with drawing better concept maps.

> I might miss some concepts about the exploration of a battery; however, after discussing with peers, I could collect more concepts.

> I could collect some concepts, which I did not know while discussing with others. Group discussion also helped me with arranging the proposition in my concept map.

However, a small number of students (E1:18%; E2:21%) felt it was troublesome to draw concept maps since the students were unfamiliar with using collaborative concept mapping in the beginning. They think that drawing concept maps is difficult and consumes too much time to do it. Furthermore, a situation occurred in which only a few students were constructing concept maps in the groups, and others were just copying the completed concept maps. The reason was because the concept mapping was carried out using paper and pencil, with the complexity of drawing concept maps, it often required a significant amount of time to accomplish. The following are the responses from the student interviews and learning journals:

> I think drawing concept mapping related to an electric circuit takes too much time and it is troublesome as well.

> I feel concept mapping was difficult to draw and we spent most of the time on arguing. Besides, only a few people were constructing concept maps, the others were just copying the completed concept maps.

Coteachers' Instant Feedback and Students' Journal Writing Could Guide and Examine the Students' Concept Maps to Facilitate Their Cognitive Learning

Some of the students had negative views on drawing concept maps because they thought it was troublesome to write down many words, difficult to draw and arrange proposition, and time-consuming. In order to avoid the aforementioned reasons that affect the students' learning interests, coteachers provided instant feedback and examined the students' knowledge framework through their verbal presentation; thus coteachers could provide their roles of guidance. For instance, Teacher Ann would provide sufficient opportunity for the students to express themselves; therefore, when the students had misconception, she would lead them to redo the process of thinking, discussing, and presenting. Alternatively, she would ask the students to stay after class to clarify and correct their misconception.

> Today, John's presentation diverged from the main theme. I therefore asked questions to make him rethink again and correct himself. If I did not ask any questions, it would have ended up in a misconception. [Teacher Ann's handbook]

Having the students to write their learning journal and present it was considered as an effective way for them to examine themselves and learn from peers. In order to check the students' understanding, coteachers would ask the students to draw concept maps and write down their feedback and suggestions in their learning journal. Then, the students had to present their concept maps and learning journal. In this case, they could share and observe peers work. Moreover, coteachers would collect and correct the students' learning journals, and would give the journals back next time when the students would draw concept maps. Therefore, the students would know their mistakes and correct themselves, and improve their concept maps.

> How do we record the students' learning process? The answer is to ask the students to write their learning journal. By making them get on stage to present their work not only could train their verbal

expression ability but also could provide the opportunity for them to observe and learn from peers. [Teacher Bee's Interview]

Influence of Coteachers' Attitudes on Teaching Performance

Table 2 indicates that most of the students (E1:79%; E2:76%) were satisfied with the curriculum in this semester, which proves that the experimental teaching method used in this research has positive impact on the students' learning performance. Besides the impact from the integration of "collaborative conccpt-mapping and co-teaching" on the aforementioned statement, the way that both teachers collaborated could affect students' study attitudes. It seems that good interaction and cooperation among team teachers could set a model for the students in the implementation of collaborative learning. The following was a student's response:

> I found that the two collaborative teachers complemented each other in many ways. Teacher Ann was good at concept-map drawing, whereas, Teacher Bee know how to implement collaborative learning very well. Their collaborative attitude set a good example for us to work together as a group.

It is also found that team teachers' attitudes toward the experimental teaching would affect the teaching performance in this research. The first challenge to teachers who participated in the coteaching springs from themselves. A successful coteaching depended heavily on teachers' communication skills, willingness to compromise, and abilities of self-reflection. Teachers used to prepare teaching materials by themselves. So, when discussions with others are required in coteaching, they need to learn to accept others' opinions and to retain optimistic attitudes. If the teachers were willing to cooperate with one another, they would learn new things from each othcr and cnjoy team teaching. The researcher found that collaborative teachers were very considerate and willing to help each other in this study. In the process, they even experienced an elevating contentment, improving their view on collaboration and resulting in an even better teaching performance and cooperative relationship.

> We knew each other very well before the co-teaching classes. Hence we quickly enter the situation with a cooperative and positive attitude. In this study, I will not only enjoy a pleasant co-teaching experience but also learn a lot from it. [Teacher Ann's interview]
>
> Everybody shared and contributed for this class. In the end, we were able to realize ideas that we could not make the outcomes if we worked separately. The sharing of work and co-teaching, and the showing of mutual understanding gave the greatest contentment to our heart and soul from the cooperative process. [Teacher Bee's interview]

Implications and Conclusion

The specific contribution of this study provided the empirical evidences to show that the teaching method of integrating collaborative concept mapping and coteaching did have some impact on students' performance. Although the researcher cannot determine the reasons from these statistics, from student responses, it was clear that students believed collaborative concept mapping enhanced their understanding of the science lessons as similar to some researches (Liu, 2004; Novak, 1998; Roth & Roychoudhury, 1993; Wellington & Osborne, 2001; Yin et al., 2005). Collaborative concept-mapping teaching emphasizes on learning materials that should be based on the student's existing knowledge, and values the connection between student's existing and new knowledge. It can increase communicative opportunity for students to help them organize the content in order to understand better. Students' presentation can refine their concepts so as to make their concepts more logical and explainable. In addition, some students believed that coteaching could have the teachers share their expertise with one another. For that point, it could facilitate the implcmentation of collaborative concept mapping and student's concept-mapping construction. It could also modify their concept construction and discover missing concept, thus, make their conceptual understanding complete. Therefore, a teaching method including two simultaneous interventions should be conducive to students' final exam performance.

Moreover, the rescarch found that the strategies of collaborative learning and team teachers' attitude could affect the students' learning performance. Constructing concept mapping collaboratively can improve the learning performance rather than

working independently. It is believed that the way of collaborative learning helps students exchange their ideas and learn from each other. During the interaction, the more capable peers can assist the slow learners through scaffolding to accomplish concept mapping within the zone of proximal development and to refine concept mapping. One must also be aware of the situation that some students only copy others' concept maps without conceiving by their own. In a coteaching situation, the class had two teachers in the same classroom, and the two teachers taught different parts of the subject respectively in a cooperative way. Typically, both teachers already had a normal teaching assignment and coteaching would increase their additional teaching assignment. However, the study shows that coteaching technique is interesting and new to students, and is more attractive than the traditional teaching method. Furthermore, this research found that teachers benefited from coteaching, because the implementation of coteaching not only provided them with the opportunities to collaborate and assist one another in teaching, but also improve interaction and friendship between teachers. In addition, the way that both teachers collaborated could affect students' study attitude. The researcher believes that if the coteachers can set up a good example of collaborative teaching in front of the students, the students may be influenced to process the effective collaborative learning.

Collaborative concept mapping is a way through graphs to see the appearance of students' knowledge framework, which is easier for teachers and students to correct their mistakes or misconceptions. It may also help both teachers and students become more proficient in understanding science (Novak, 2005). Novak and Gowin (1984) indicate that when facing complex concepts, one could use graphs to systematically categorize concepts into nodes and use labeled lines to link each concept, turning teaching content into graph system that is easy to learn and memorize, thereby facilitating the understanding of teaching content by drawing concept maps. The process of drawing concept maps on the learning journal was considered as an effective way for students to examine their understanding. In this case, journal writing should help experimental students' performance in this study. Furthermore, coteachers would collect and correct the students' concept maps, and would give them back next time. Therefore, the students would know their misconceptions and correct themselves, thus improving the concept maps. Moreover, through the process of students' presentation, they shared their opinions and learned from each other, thus they ensured the completeness of the concept maps. Therefore, the experimental teaching strategy has its advantages in these respects.

This study also found some limitations about the students' negative views on drawing concept maps because they found it was troublesome to write down many words, difficult to draw and arrange propositions, and time-consuming. The limitations of the study are also the small number and a fixed grade of participants. Thus, the results are limited to inference. Therefore, a more in-depth research on exploring the effects of incorporating collaborative concept mapping with coteaching on a considerable amount of participants with different grades, in a particular gender (males or females) or student's ability (high or low achievement of students), has been suggested for future research. The research methods of integrating collaborative concept-mapping and coteaching techniques could increase the learning and research experience of both science teachers and the researcher, and also serve as useful references for other teacher education institutes.

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Author's Note

Keywords: Collaborative concept-mapping; coteaching; collaborative learning; journal writing; social constructivist approach.

Scientists and Science Educators Mentoring Secondary Science Teachers

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This paper examines secondary science teachers' perspectives of the role that mentoring by a scientist and science educator pair played in their professional development. Multiple data sources from three years of a professional development project, including interviews, participant reflections, and a focus group, were used to examine the benefits, supporting characteristics, and challenges of the mentoring relationship. Results indicated that primary benefits of the mentoring included assistance in translating science content and inquiry-based pedagogy from the professional development into practice and breaking the isolation felt by secondary science teachers. Specific characteristics that were found to support the teachers in the mentoring relationship included: (1) mentors who were seen as objective, outside observers; (2) a sustained relationship with the mentors; and (3) accountability. Challenges included matching scientists' and science educators' content expertise with teachers' curriculum and the negotiation of roles and expectations between the teachers and mentors.

High-quality professional development programs should be (1) sustained, (2) focused on subject-matter knowledge, (3) connected to student work, (4) collaborative, and (5) embedded in practice (Darling-Hammond & McLaughlin, 1995; Suppovitz & Turner, 2000). There is no one perfect model of professional development (Guskey, 1994). When preparing professional development activities, the model employed will depend on the goals of the professional development program and the stage of teacher learning. Furthermore, Loucks-Horsley, Love, Stiles, Mundry, and Hewson (2003) asserted that a combination of models is often necessary to accomplish professional development goals.

However, few studies have examined the benefits and limitations of combining various models of professional development. Our professional development project focused on improving secondary science teachers' knowledge of science content and scientific inquiry while providing school-based support for the translation of this knowledge into classroom practice. In order to accomplish these goals and address all five characteristics of high-quality professional development, we designed a professional development model that combined workshops with school-based and online mentoring (Loucks-Horsley et al., 2003). The mentoring component of this model partnered science educators with scientists in order to provide ongoing support for teachers (Sussman, 1993). This paper examines teachers' perspectives of the role that mentoring by scientists and science educators played in their professional development.

Traditionally, scientist–teacher partnerships have supported teachers by expanding their content knowledge, broadening their understanding of scientific inquiry, or increasing their awareness of scientific careers (Timourian, 1993). However, these partnerships have often involved limited follow-up to assist teachers with incorporating content and pedagogical knowledge into classroom practice (Loucks-Horsley et al., 2003). Mentoring, on the other hand, provides on-site support for teachers directly focused on instructional practices. Mentors are often more experienced teachers or education faculty (Koch & Appleton, 2007) who are skilled with regard to pedagogical approaches, but not necessarily knowledgeable regarding subject-matter content. Combining scientist–teacher partnerships with mentoring by scientists and science educators provides an opportunity to combine the content expertise of the scientists and the pedagogical expertise of the science educators with the ongoing support provided by mentoring.

This paper draws from the evaluation of a professional development project in order to examine the benefits, supporting characteristics, and challenges of this approach.

Background

Effective Professional Development

Principles of effective professional development emphasize enhancement of teachers' content and pedagogical knowledge, recognize change as an individual and organizational process, and encourage collegiality and collaboration (Borko, 2004; Guskey, 1994; Loucks-Horsley, Styles, & Hewson, 1996). Various models of professional development exist, and opportunities for teacher learning can occur both inside and outside of the classroom. Historically, most of the professional development that teachers engage in occurs outside of the school day at workshops and conferences separated from their school context (Garet, Porter, Desimone, Birman, & Yoon, 2001). This type of workshop-based professional development generally involves a leader or leaders with special expertise and participants who attend sessions at scheduled times — often after school, on the weekend, or during the summer (Loucks-Horsley et al., 2003).

Alternatively, school-based professional development provides teachers with support and learning opportunities that are embedded in the teachers' daily activities. Ongoing classroom-based support is a critical component of effective professional development efforts. A study of teachers involved in local systemic change projects found that at least 80 hours of professional development were required to increase teachers' use of inquiry-based teaching practices above that of the average teacher (Suppovitz & Turner, 2000). Furthermore, Garet et al. (2001) suggested that professional development that is embedded in the daily life of the school is more likely to produce enhanced knowledge and skills than traditional forms of professional development.

Scientist–Teacher Partnerships

Scientist–teacher partnerships may involve one-on-one relationships between a teacher and a scientist or may involve scientists in professional development with multiple teachers (Loucks-Horsley et al., 2003; Moreno, 1999). Scientist–teacher partnerships provide teachers with support from someone who is knowledgeable about both science subject matter and the processes of scientific inquiry. These partnerships have the potential to increase teachers' content knowledge and understanding of scientific inquiry and provide real-world examples of the applications of subject matter (Loucks-Horsley et al., 2003). On a broader scale, scientist–teacher partnerships can facilitate more coherent science education from K-12 through higher education (Tanner, Chatman, & Allen, 2003).

Historically, scientist–teacher partnerships have considered the scientist as the expert in the partnership. The scientists' role has been primarily to provide teachers and students with technical and subject-matter expertise. However, current views of scientist–teacher partnerships recognize the mutual benefits of mentoring in these partnerships (Loucks-Horsley et al., 2003). Moreno (1999) described successful scientist–teacher partnerships as characterized by "mutual respect and genuine appreciation of the roles played by each participant" (p. 575).

Scientist–teacher partnerships must also recognize the importance of connecting the partnership to the school context. Sussman (1993) emphasized the many dimensions that must be considered in developing effective partnerships:

> Teachers need instruction in new content and skills; they need lessons and materials that embody the new philosophy; they need samples of and training in alternative assessment tools; and they need support back in the school and the community or else the vast inertia of the existing school culture will doom all our efforts (p. 11).

Mentoring

Mentoring and coaching are professional development strategies that sustain "long-term, ongoing professional learning embedded within the school culture" (Loucks-Horsley et al., 2003, p. 219). Mentoring often consists of a relationship between a student teacher or new teacher and a more experienced teacher (Anderson & Shannon, 1988), while coaching often occurs between two experienced teachers (Loucks-Horsley et al., 2003). These terms are often used to describe similar practices. We use the term "mentoring" to refer to the relationship between the scientist and science educator and the teachers. Yet for the purposes of this article, we draw on the literature from both mentoring and coaching.

Professional development that is embedded within the school context acknowledges the importance of situated learning (Lave & Wenger, 1991). Knight

(2002) pointed out that "something taught in an in-service course has a transfer value and a life expectancy directly proportional to its fit with the community of practice, which provides a way of understanding why continuing professional development courses often have such limited influence on activity" (p. 232). Mentoring that occurs as follow-up to professional development workshops provides support for implementation of new knowledge and pedagogical practices through guided practice within specific classroom contexts. This specific form of mentoring can help teachers transfer learning to their classrooms and improve practice without fear of evaluation (Neufeld & Roper, 2003). Furthermore, research on peer coaching has found that coached teachers practiced new strategies more frequently and used them more appropriately than teachers who are not coached (Joyce & Showers, 2002).

Both scientists and science educators acted as mentors in this project. Science educators have expertise in both education and science and can therefore mentor teachers in both content and pedagogy. For example, Bencze and Hodson (1999) examined teachers involved in a collaborative action research project in which a university-based science educator acted as a facilitator while the teachers worked to design and implement more authentic science instruction in a grade 7 classroom. The science educator supported teachers in changing their views of science and science teaching and encouraged the use of new instructional practices.

The mentoring in this project included both face-to-face and online interactions. The increasing availability of computer technology has resulted in rapid and universal growth of computers as an educational tool. Online teacher support programs, for both preservice and in-service teachers, have been demonstrated as a means for effective science support (Annetta & Shymansky, 2006; Barab, Makinster, & Moore, 2001; Harlen, 2004). Participation in online discussions provides teachers with access to others outside of their schools and promotes reflection on current teaching practices.

Research Questions

The focus of this study was on the teachers' perspectives of the role that mentoring from the scientists and science educators played in their professional development. To examine the nature of this relationship, we asked the following research questions:

1. What aspects of the mentoring relationship did teachers find most valuable?
2. What characteristics of the mentoring structure in this professional development program supported the mentoring relationship?
3. What challenges emerged that hampered the mentoring relationship?

Methods

Participants and Context

Each year a new group of middle and high school science teachers participated in the professional development project that is the focus of this paper. A total of 41 teachers participated over the three years of this project. Some teachers only participated in the summer workshop and then withdrew from the project. Teachers withdrew following the summer workshop for various reasons, including medical issues, workload concerns during the school year, and changes in teaching assignments. Since this paper focuses on the mentoring component of the project, participants were only drawn from teachers who remained in the project during the school year. This included six teachers from year 1, 10 teachers from year 2, and nine teachers from year 3. From this pool, a total of 18 teachers were involved in interviews, focus groups, and/or completed mentoring reflections. Information regarding the teacher's year of participation, grade, subject area, and participation in the data collection are provided in Table 1.

The primary goal of the professional development project was to develop the content knowledge and pedagogical skills of teachers in order to improve student achievement in mathematics and science. The project began with a two-week summer workshop and continued throughout the school year. During the summer workshop, teachers studied science content based on watershed ecology and hydrology along with inquiry-based teaching strategies for implementing this content into their curriculum. Project staff engaged teachers in inquiry-based lessons with a focus on specific science content. Active learning experiences were followed by explicit discussions of the pedagogical strategies that were used and issues related to applying similar practices in secondary classrooms. The scientists and science educators in the project worked collaboratively to develop and to teach the activities used in the summer workshop.

Project staff consisted of scientists and science educators. The scientists included a professor of ecology

Table 1
Participant Information by Cohort

Cohort	Number of participants	Grade (subject taught)	Data provided
Year 1	5	6 (science, health, literacy)	I
		6-7 (life science, earth science)	I
		6 (general science)	I
		9-12 (biology)	I
		7 (integrated science)	I
Year 2	4	6-8 (all subjects-special needs)	I
		6-8 (all science subjects)	I
		6-7 (life science, earth science)	I
		6-8* (all science subjects)	I
Year 3	6	7-8* (all science subjects)	I, FG, MR
		9-12 (biology)	I, FG, MR
		9-12 (earth science, biology)	I, FG, MR
		7-8* (all science subjects)	I, FG, MR
		10-12 (biology)	I, MR
		6 (integrated science)	MR
		6 (all science subjects)	MR
		6-8* (all science subjects)	MR
		9-11* (all science courses-special needs)	FG

* The only science teacher in their school.
I = interview, FG = focus group, MR = mentoring reflection.

and two graduate students in geology/hydrology. The science educators included a professor of science education and two graduate students in science education. This was consistent for all three years of the project except for one graduate student in science education who participated for the first two years and was replaced by another science education graduate student in the third year. The science educators had experience teaching secondary science, as well as degrees and research experience in science content areas related to ecology.

During the school year, teachers conducted action research projects and participated in one-day workshops, classroom-based mentoring, and online discussions. During each school term (fall, winter, and spring), teachers conducted action research projects where they identified a question related to the content or pedagogy from the summer workshop to investigate in their classrooms. For one school term, they were required to focus their action research project on developing a unit of instruction on watershed ecology, geology, or hydrology. At the end of each term, the teachers attended a one-day workshop where they shared the results of their action research projects including lessons they developed and examples of student work.

Structure and Implementation of the Mentoring

The project paired scientists and science educators in order to provide ongoing classroom-based mentoring for each teacher. Both the scientist and science educator were present at all classroom visits. Before the start of the site visits, the teachers were asked to

identify which scientist they would like to partner with for the school year mentoring. Attempts were made to match the content expertise of the scientists and science educators with the content focus of the teachers' curriculum. Mentors conducted one site-visit per term, making three visits throughout the school year.

Prior to each visit, the teachers sent an email through the project's website with basic information about their lesson plans, including a description of the objectives, inquiry-based teaching, and content to be taught. On the day of the site visit, the mentors observed the teacher during one class period. Following each observation, the mentors met with the teacher for 30 minutes to an hour to discuss the observed lesson. During these discussions, the teachers were asked to share what they thought went well, what they struggled with, and any issues they wanted to discuss. The mentors then discussed with the teachers additional things that they saw that went well, along with things that could be improved. When there were things that could be improved, the mentors first focused on something specific that they saw occur in the class and then followed that by providing possible alternative ways of approaching the situation.

In between the site visits, the mentoring was continued through a discussion board on the project's website where teacher posts were responded to by project staff and other teachers. The online mentoring was flexible, interactive, and continuously available. Teachers were encouraged to post questions, ideas for future lessons, and reflections on past lessons. To ensure participation, the teachers were required to post to the discussion board at least 10 times during each term.

Data Collection

Data collection for this project included individual phone interviews with teachers from all three years of the project conducted as part of the project evaluation. Additional data including a focus group and mentoring reflections were collected from Year 3 participants in order to examine more deeply the mentoring component of this project.

Individual phone interviews. Interviews were conducted with five teachers from year 1, four teachers from year 2, and five teachers from year 3 (Table 1) and were designed to gather information about the project as a whole including specific aspects such as the mentoring component. In the interviews, teachers were asked to describe: (1) their overall assessment of the project; (2) the nature of the mentoring they experienced; (3) how successful the project was in providing combined support for both content and pedagogy; (4) the fit between the content and pedagogy emphasis of the project and the instructional priorities of their school; (5) how helpful the on-site visits were; and (6) what long-term effects the project had on their teaching, in regards to inquiry-based teaching and increased content knowledge. Phone interviews were audiotaped and transcribed.

Focus group. A focus group consisting of five participants from year 3 was asked to describe their experience with mentoring by the scientist and the science educator during the project. This included a general description about how they felt about it, what they saw as its value, what they saw as differences between the scientist mentor and the science education mentor, and what they learned from the experience. The focus group discussion was audiotaped and then transcribed.

Mentoring reflections. During a workshop held in December of the third year of the project, teachers were asked to respond to questions regarding their experiences with the mentoring. Specifically, they were asked to describe what aspects of the mentoring they found useful or not useful and what would they change.

Data Analysis

Individual phone interviews, the focus group, and mentoring reflections were reviewed and individually coded by two researchers. Qualitative data analysis followed closely that of Auerbach and Silverstein (2003) where each researcher independently identified themes that emerged from the analysis. Following the initial coding, the researchers compared and combined the independently identified themes. After the themes were identified, the data were reexamined to identify confirming and disconfirming evidence of the themes.

Results

The results will be discussed in three sections related to the research questions (1) aspects of the mentoring relationship that teachers found valuable; (2) characteristics that supported the mentoring relationship; and (3) challenges to the mentoring relationship.

Valuable Aspects of the Mentoring Relationship

When asked about helpful aspects of the mentoring, teachers described the roles that the mentors played in providing assistance with science content, modeling of content-specific pedagogical strategies, and science-specific resources and feedback.

Providing assistance with science content. Some of the teachers found that having the mentors visit their class was valuable for them to improve areas of science in which they felt weak and to receive assistance in implementing content learned from the summer workshop into their curriculum. One teacher reflected that "It was great to have someone there to bounce ideas off . . . Having people in my class who were knowledgeable about science was most valuable. I could ask them questions and get answers" [Yr 3, Interview]. This teacher also added "I would like more professional development like this, taught by people who know science rather than a typical education course" [Yr 3, Focus Group].

The mentoring also supported teachers in applying the content that they learned in the summer workshop to their classroom instruction. One teacher described how the mentors were "here to give us ideas and help us incorporate them . . . here is the content and now we are going to help you use it rather than just telling us what it is" [Yr 3, Focus Group]. Teachers, in general, found the mentors' expertise to be useful in helping them to develop their science content knowledge and to implement content from the summer workshop into their classroom instruction.

Modeling content-specific pedagogical strategies. Some of the teachers noted the role of the pedagogical support, especially in regard to inquiry teaching, as particularly helpful in the mentoring partnership. Teachers explained that during the school year, they implemented some of the inquiry-based techniques they learned in the summer workshop, and that participating in the project had challenged them not only to think about but also to implement inquiry methods. One teacher commented (a year after completing the program): "Learning more about how to conduct inquiry based instruction was the most valuable to me" [Yr 2, Interview]. He discussed the long-term impact of the program on his instruction, "I'm more inquiry based than I was before" [Yr 2, Interview].

During the classroom visits, mentors often walked around the classroom and interacted with the students. Some teachers found this to be particularly helpful as a way to observe teaching strategies that were modeled by the mentors. One teacher reflected on her experiences observing her mentor during a stream table inquiry:

> One of the . . . [mentors] had just gotten through questioning one of my students, just really effective, "where do you see the erosion happening? Where do you see the build up?" Just really simple questions, but it really helped me because I just wasn't sure how to approach this activity. And so when I heard her doing that, I of course, grabbed a hold of it and I started doing it. She was modeling for me. I don't know if she was intending to model for me, but that's what it was, for me. . . . I did that at the summer institute, I made the same stream tables, but that was a long time ago. . . . So it was really nice for me to do that, I immediately grabbed it and I practiced with every group that I was able to get to. [Yr 3, Interview]

The presence of the mentor and the modeling of questioning strategies in the classroom site visit reminded the teacher of particular pedagogical strategies introduced in the summer workshop and helped this teacher incorporate these strategies into her own teaching. This suggests that the modeling during the classroom site visit was an important factor in this teachers' implementation of summer workshop ideas.

Providing science-specific resources and feedback — breaking the isolation of teaching. Many teachers found that the mentors served as a resource by providing new ideas, making observations, and providing feedback. Following the observations, the mentors would sit with the teachers and discuss their unit/lesson plans, their science content, inquiry, and other pedagogy questions, and would provide feedback and suggestions based on the observations.

Teachers often described how having the mentors visit their classroom helped break some of the isolation that they experience as teachers. Similar to many other reflections, one teacher remarked:

> Being the only science teacher at my school, most other teachers have no opinions or feedback on the science content teaching and learning. But having the mentors come visit was great for brainstorming, reflecting, and even affirmation that things went well. [Yr 3, Interview]

This teacher felt that having mentors who were specifically engaged with her material were particularly helpful. She also stated: "To have someone else to talk to who has ideas has been invaluable" [Yr 3, Interview]. Another teacher described how the mentoring helped break the isolation he experiences in the teaching profession:

> I felt the feedback that the mentors . . . provided was the most valuable part. . . . They were helpful. The science education mentor was very much into the pedagogy. Teaching can be a very isolated profession. You don't very often get to have someone come in and observe you and provide feedback without an agenda. My training in teaching was very limited. [Yr 2, Interview]

Characteristics that Supported the Mentoring Relationship

There were three main themes regarding the characteristics of the mentoring structure that supported the teachers: (1) having objective, outside observers, (2) a sustained relationship with the mentors through the use of technology and site-visits, and (3) accountability that facilitated their implementation of the content and pedagogy from the summer workshop.

Objective outside observers. Teachers found it helpful to have outside observers who were not tied to the district, and they commented that they felt the outside observers were more neutral, or objective, than in-house or district observers. One teacher commented: "Having a neutral perspective was helpful in learning what was going on. To have an outsider coming in who doesn't have the prejudices" [Yr 3, Focus Group]. Another teacher shared that she was interested in knowing how her teaching compared with what was happening at other schools:

> I felt that my fall site visit from the mentors was very helpful. Sometimes I get bogged down in my teaching and I don't know how my students' learning and my teaching compare to what is going on in other schools, so it is good to have objective observers that are not connected to my own district or evaluation. [Yr 3, Mentoring Reflection]

Sustained relationship throughout the school year. Having a sustained relationship, through the mentoring and the use of technology, helped facilitate the teachers' implementation of summer content and instructional strategies into their school year curriculum. One teacher discussed how the project's online discussion board helped her to retain course information and encouraged her to use this information in her classroom:

> With any professional development that occurs in the summer, you learn but then you forget about it by the winter and ignore it. Having the thread go throughout the year with the periodic visits and [the project's on-line discussion board] really helped me to retain the information and make the conscious effort to incorporate the material into my lesson plan. [Yr 3, Focus Group]

Another teacher explained that the discussion board helped her to learn about how to implement scientific inquiry into her classroom by providing assistance and resources when needed:

> I felt that I was learning instructional strategies through [the project's on-line discussion board] when I needed it, when I had a question. It was more about sharing ideas and tools rather than learning about a philosophy, we all knew the philosophy behind scientific inquiry. How to do it was what we learned. [Yr 3, Focus Group]

The online discussion board assisted teachers with implementing new content and instructional strategies by providing just-in-time learning opportunities. The online discussion component created an online community that facilitated additional mentoring opportunities throughout the year.

Accountability. Some of the teachers felt that the structure of the mentoring component held them more accountable for implementing content and pedagogy from the summer workshop. One teacher compared how the year-long structure of this professional development project differed from that of her past professional development experiences:

> In a lot of courses or workshops, you get pretty excited about it at the time you're doing it. You know it may have been a make and take workshop and you're excited and energized by it, and then you get back into the classroom and all of that fizzles out because there's no support there. And I think with this being a year long . . . there was some really good wisdom in making it a year long because then they get the support of the staff and of the other teachers in the cohort, who may be at the same grade level as you for asking questions, for being a resource. . . . So here I am, you know a year after the cohort and I'm still using that stuff. I've been to a lot of in-services and workshops

where they get the coursework done and then it's over. This has really been something that I incorporated into my teaching. [Yr 2, Interview]

Another teacher specifically commented on how the mentoring aspect of the project held her accountable:

With the observations, I was kept on my toes. I had to think using the specific method and take extra care with my lesson plans, and you question your strategies. It kept me from being complacent. Having used the materials (content and pedagogy) all year meant it was more likely to stick. [Yr 3, Focus Group]

In summary, teachers discussed several parts of the structure of the mentoring that were useful to them, including the objective perspective of the mentors due to their place outside of the school district, the sustained relationship facilitated through the use of classroom visits and technology, and the year-long component of the project that held them accountable to incorporate the content and pedagogy from the summer workshop throughout the school year.

Challenges with the Teacher–Mentor Relationship

Although the project appeared to have many benefits to the teachers and positive impacts on teachers' practices, teachers also identified challenges that occurred during the mentoring relationship. As discussed previously, one of the mentors' roles was to provide content expertise and support. However, it was sometimes difficult to match the scientists' content expertise with the content of the teachers' curriculum. The scientist mentors were specialized in areas such as ecology, geology, and hydrology. This matched with the content taught in the summer workshop. However, throughout the school year, many of the teachers taught subjects that included biology, chemistry, physics, and earth science. It was not always possible to match the expertise of the scientist to the content the teachers were focusing on during each term. One teacher reflected, "for the most part, I was more of the content expert than either of them because their visits were during my chemistry or physics classes" [Yr 3, Focus Group]. The aim was to best match the content of the scientist mentors to that of the teachers' curriculum. However, when this was not possible, the mentors would visit and focus on pedagogy and on developing future lessons or units. One teacher reflected on this logistical difficulty, "they are content experts, but they are content experts in a very specialized area. . . . When you are teaching a broad array of stuff, it is unlikely that they will be there during the time that matches their expertise" [Yr 3, Focus Group].

Although the teachers appreciated the support and feedback that they got from the mentors, some teachers expressed that having the mentors in the classroom felt stressful or intrusive at times. One teacher stated that:

I found the onsite visits, as much as I really liked and enjoyed the people, but I felt like . . . it was almost intrusive to me, to be perfectly honest. To have the people come into the classroom. Because I felt like I was back doing the student teaching thing and they were expecting me to put on . . . all this extra preparation type stuff. . . . It usually doesn't bother me to have people in my classroom, to come in and watch what's going on, but usually that's because I'm the science person and they're not. [Yr 1, Interview]

Teachers also commented that while they were nervous at first about the site visits, over time they tended to feel less stressed, "At first I was nervous about having someone in my room but after the first visit, it was laid back and we got a lot of useful feedback" [Yr 3, Focus Group].

Another challenge experienced in the mentoring relationship involved the negotiation of roles and expectations between the teachers and the mentors. Some of the teachers expressed that they would have liked the mentors to participate more fully in the class during the visits and would have liked clearer discussions in the beginning of the mentoring relationship regarding expectations for the classroom visits. One teacher reflected on her experience, where she felt there were not clear expectations about how the mentors should interact with the students:

I felt like I should have been really clear up front, about what I wanted . . . [the mentors] to do . . . If they did what I wanted them to they would have walked around the room, observed, pointed to things that needed to be (unclear) . . . walked around the room and sort of helped co-facilitate. Then on their second visit they were absolutely perfect. They did exactly what I wanted them to. [Yr 3, Interview]

Some of the teachers also felt that they would have liked the mentors to take on more of an active role. For example, one teacher described how she would have liked to have the scientists as guest speakers:

> I would have loved to have had them come in as guest speakers, to lead the class. That would have been fantastic, to see them model teaching in our class would have been awesome as opposed to having them observe and provide pointers. I don't get to see enough teachers. I don't feel that I have enough tricks. Without strong examples it is hard for me to be creative. [Yr 3, Focus Group]

The relationship between the scientist, the science education mentors, and the teachers experienced some challenges that were common to all mentoring relationships and others specific to the science content focus of the mentoring. Teachers' nervousness about having mentors in the classrooms and the negotiation of roles are common challenges with mentoring (Denmark & Podsen, 2000; Neufeld & Roper, 2003). However, the challenge of matching scientists' content expertise with teachers' curriculum is a unique problem associated with mentoring by scientists and science educators. The scientists in this project were specialists in a particular area of science, whereas the teachers in the project often taught multiple science subjects.

Discussion

These results suggest that the beneficial effects of combining partnerships and mentoring with a combination of off-site workshops and ongoing classroom interaction support the use of this model of professional development in science education. The combination of strategies utilized in this professional development model results in benefits to teachers that exceed what any of the strategies could accomplish in isolation.

In most projects which team scientists with teachers, the scientists primarily serve as a resource for science content and processes, and the teachers or other educators are left to make the translation between the content and pedagogical practices (Fedock, Zambo, & Cobern, 1996). In most mentoring relationships, the mentor is knowledgeable about pedagogical approaches, but often less knowledgeable about the specific content and processes of the discipline. In this project, scientists and science educators provided teachers assistance with science content, modeling of content-specific pedagogical strategies, and provided science-specific resources and feedback. This assisted the teachers in translating the science content and inquiry-based pedagogy from the professional development workshop into practice. Having scientists and science educators act as mentors allowed for a combined focus on both content and inquiry-based pedagogy. Having science educators with science content background partner with scientists who had participated in the development and instruction of inquiry-based teaching during the summer workshop further supported this combined focus.

Specific benefits of the scientist and science educator partnership in the mentoring relationship examined in this study included lessening the isolation felt by science teachers, eliminating the perception of mentors as evaluators, and sustaining the mentoring relationship through a combination of approaches. Although teachers interact with colleagues and students multiple times during each day, they often describe feeling isolated (Goodlad, 1984). Secondary teachers may be more likely to feel this isolation, because they are often considered the content experts at their schools and therefore are less likely to consult with colleagues regarding issues related to teaching their subjects. Many of the teachers in this study described how the mentoring helped break the isolation of teaching. It is possible that any mentoring would help break the general isolation of teaching. However, the impact of mentors that were knowledgeable about science content and specific issues related to teaching science provided support that was not being provided by other colleagues.

In many forms of mentoring, the mentor is often in either a collegial or supervisory role in which the teachers may see the mentors as directly or indirectly evaluating their teaching. The mentor's assessment role may cause reluctance among teachers to seek advice from their mentors (Youens & McCarthy, 2007). In this project, the teachers initially felt nervous about having the mentors in their classrooms, but over time this perception lessened. We found that pairing teachers with mentors that were not connected to their schools or districts benefited the mentoring relationship by allowing the teachers to perceive the mentors as more neutral and objective.

The combination of classroom visits and online discussion forums helped sustain the mentoring

relationship throughout the year. The classroom visits provided face-to-face on-site support, but this only occurred three times during the year. The online discussion forums created a bridge between these on-site visits and provided just-in-time learning experiences throughout the year when teachers needed support.

The mentoring encouraged and motivated teachers to apply knowledge and skills from the summer workshop into classroom practice. Key aspects of the mentoring relationship that appeared to support this included the combined focus on both content and pedagogy provided by the scientist and science education mentors and the sustained mentoring relationship provided by both classroom-based and online interactions.

Lessons Learned

The following are considerations for implementing the scientist and science educator partnership model for mentoring teachers based on teachers' experiences with this project.

The mentor's roles are multifaceted and should include a focus on both content and pedagogy. Historically, scientist–teacher partnerships considered the scientist as the expert in the partnership. The scientist's role was primarily to provide teachers and students with technical and subject-matter expertise. However, the mentoring component of this project required scientists to incorporate additional roles that combined content and pedagogical support by providing instructional resources, feedback, and modeling. These are not familiar roles for scientists, and the science educator was able to help bridge the gap between the scientist's content expertise and the teacher's pedagogical needs.

The mentoring relationship should be viewed as a partnership and not an evaluation or judgment. Teachers may initially feel intimidated by having others in their classrooms. Therefore, those in mentorship roles should acknowledge, respect, and learn about teachers' expertise and context in order to build a relationship that removes the evaluative focus for the teachers. In addition, it is important for teachers to feel that their mentors are allies and colleagues to enhance practice. A common theme that emerged from teachers' interviews was that they generally felt comfortable having the mentors come into their classroom because they knew they were not being evaluated. If mentors are able to establish a safe and trusting environment where teachers are not afraid of criticism or evaluation, teachers will be more likely to engage in such a partnership, and embrace improving their practice.

Mentoring visits should be coordinated so that the expertise of mentors is specific to the teachers' curriculum when possible. Science is a broad field that includes many disciplines. Scientists generally specialize in specific areas of science. However, most science teachers teach a range of science content within their classes. In scientist and science educator partnerships involving mentoring, it is important to attempt to coordinate the expertise of the mentor with the teachers' curriculum. The teachers in this program felt they benefited the most when their mentors' expertise matched the curriculum they were teaching. However, when this is not possible, the scientist mentors can still assist teachers with issues related to scientific inquiry and implementing inquiry-based teaching strategies.

A sustained relationship throughout the year provides support and increases the likelihood that teachers will be able to successfully implement the lessons of the initial workshop. Efforts should be made to sustain the mentoring relationship throughout the school year. A combination of strategies, including school visits, off-site workshops, and online discussion, can be utilized to provide support and maintain the mentoring relationship. This combination of approaches increases teachers' accessibility to their mentors and their sense of accountability to continue to incorporate ideas from the professional development. Teachers commented that this model is distinctly different from other short-duration professional development projects they have participated in the past where they learned new content and instructional strategies but did not fully implement changes.

This study illustrates the value of scientist and science educator partnerships in mentoring teachers. This relationship provided an opportunity to bridge the gap between science content and pedagogy through the combination of the scientist's expertise in science content, the science educator's expertise in pedagogy, and the teacher's expertise in teaching and knowledge of the classroom context. This mentoring relationship supported teacher's implementation of content and pedagogy from workshops through sustained interactions during the school year, which utilized both classroom-based and online mentoring. In addition, the mentoring relationship is most successful when the scientist's area of science content expertise is closely matched to the teacher's teaching

assignment and the scientists and science education mentors are not seen as having an evaluative role in the mentoring relationship.

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Acknowledgments

We wish to acknowledge project team members Randall Colvin, Glen Fielding, Jesse Ford, Joe Hansen, Anne Jefferson, and Sarah Lewis. We are also grateful to Judith Devine for her data collection for this research project and the many people who edited previous versions of this article. The project was supported by a Mathematics and Science Partnership Program (MSP) Grant from the Oregon Department of Education, with federal authorization and funding through Title IIB of the Elementary and Secondary Education Act.

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972-86-477-648. Questions concerning proposals and/or solutions can be sent e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before April 15, 2010

• **5098:** *Proposed by Kenneth Korbin, New York, NY*

Given integer-sided triangle ABC with $\angle B = 60°$ and with $a < b < c$. The perimeter of the triangle is $3N^2 + 9N + 6$, where N is a positive integer. Find the sides of a triangle satisfying the above conditions.

• **5099:** *Proposed by Kenneth Korbin, New York, NY*

An equilateral triangle is inscribed in a circle with diameter d. Find the perimeter of the triangle if a chord with length $d - 1$ bisects two of its sides.

• **5100:** *Proposed by Mihály Bencze, Brasov, Romania*

Prove that

$$\sum_{k=1}^{n} \sqrt{\frac{k}{k+1}} \binom{n}{k} \leq \sqrt{\frac{n\left(2^{n+1}-n\right)2^{n-1}}{n+1}}$$

• **5101:** *Proposed by K. S. Bhanu and M. N. Deshpande, Nagpur, India*

An unbiased coin is tossed repeatedly until r heads are obtained. The outcomes of the tosses are written sequentially. Let R denote the total number of runs (of heads and tails) in the above experiment. Find the distribution of R.

Illustration: if we decide to toss a coin until we get 4 heads, then one of the possibilities could be the sequence $T\,T\,H\,H\,T\,H\,T\,H$ resulting in 6 runs.

• **5102:** *Proposed by Miquel Grau-Sánchez and José Luis Díaz-Barrero, Barcelona, Spain*

Let n be a positive integer and let $a_1, a_2, \ldots, a_n$ be any real numbers. Prove that

$$\frac{1}{1+a_1^2+\ldots+a_n^2} + \frac{1}{F_n F_{n+1}} \left(\sum_{k=1}^{n} \frac{a_k F_k}{1+a_1^2+\ldots+a_k^2} \right)^2 \leq 1,$$

where F_k represents the k^{th} Fibonacci number defined by $F_1 = F_2 = 1$ and for $n \geq 3$, $F_n = F_{n-1} + F_{n-2}$.

• **5103:** *Proposed by Roger Izard, Dallas, TX*

A number of circles of equal radius surround and are tangent to another circle. Each of the outer circles is tangent to two of the other outer circles. No two outer circles intersect in two points. The radius of the inner circle is a and the radius of each outer circle is b. If

$$a^4 + 4a^3b - 10a^2b^2 - 28ab^3 + b^4 = 0,$$

determine the number of outer circles.

SSM Publication Guidelines

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Heather R. Rodriguez, Managing Editor
School Science and Mathematics Journal
Texas A&M University
4232 TAMU Harrington
College Station, TX 77843-4232

Circulation Data:

Reader: K-graduate leaders and teacher educators
Frequency of issue: 8 times per year
Copies per issue: 3001-4000
Sponsorship: Professional organization

Publication Guidelines:

Manuscript length, 6-25 pages, including references

Review Information:

Type of review: Blind review
No. of external reviewers: Three
No. of in-house reviewers: Up to three
Fees charged to review: None
Editor considers recommendations of reviewer: Yes
Time to review: 6-7 months
Reviewers' comments: Yes
Invited articles: 5% or less

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Science, mathematics, and connections between science and mathematics for grades K-graduate and teacher education, especially science and mathematics articles that deal with assessment, attitudes, beliefs, curriculum, equity, research, translating research into practice, learning theory, alterative conceptions, philosophy and history of science, sociocultural issues, special populations, technology, nontraditional forms of instruction, and science/technology/society.

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All manuscripts must be prepared according to the 5th Edition of the Publication Manual of the American Psychological Association, typed double-spaced using a 12-point or larger font, and printed on 8 1/2- by 11-inch paper. Manuscripts should be limited to 25 pages, excluding figures, tables, and appendices. **Submissions that are not APA style or exceed the length limitation will be returned**.

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SCHOOL SCIENCE AND MATHEMATICS

Volume 110 • Number 3 • March 2010

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SSMA Official Journal of the School Science and Mathematics Association, Founded 1901

School Science and Mathematics

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School Science and Mathematics (Print ISSN: 0036-6803, Online ISSN: 1949-8594) is published in January, February, March, April, September, October, November and December on behalf of the School Science and Mathematics Association by Wiley Subscription Services, Inc., a Wiley Company, 111 River St., Hoboken, NJ, 07030-5774. Periodical postage paid at Hoboken, NJ and additional offices.

Postmaster: Send all address changes to *School Science and Mathematics*, Journal Customer Services, John Wiley & Sons, Inc., 350 Main St., Malden, MA 02148-5020.

Information for Subscribers: *School Science and Mathematics* is published in eight issues per year. Subscription prices for 2010 are: Institutional Print & Online rate: US$250 (the Americas), US$250 (Rest of World), €180 (Europe) £153 (UK). Prices are exclusive of tax. Asia-Pacific GST, Canadian GST and European VAT will be applied at the appropriate rates. For more information on current tax rates, please go to www3.interscience.wiley.com/aboutus/journal_ordering_and_payment.html#Tax. The institutional price includes online access to the current and all online back files to January 1, 1997, where available. For other pricing options, including access information and terms and conditions, please visit www.interscience.wiley.com/journal-info.

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Electronic Access: This journal is available online at *Wiley InterScience*. Visit www.interscience.wiley.com to search the articles and register for table of contents and email alerts.

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ISSN: 0036-6803 (Print)
ISSN: 1949-8594 (Online)
Printed in the US by The Sheridan Group.

IN THIS issue

Research in Brief

Gender Differences in Mathematics Learning
Zhixia You

Gender differences in mathematics and science have received substantial attention in the education research since the early 1980s when strong evidence for a male advantage was found in various studies (e.g., Benbow & Stanley, 1980; Halpern, 1986; Hyde, Fennema, & Lamon, 1990; Reis & Park, 2001). Given that mathematics is required for a variety of careers, the potential cause(s) of this disparity have generated much research — much of it conflicting with other research in regard to the nature of this difference as well as the timing of its occurrence.

Research Articles

Comparing the Development of Fractions in the Fifth- and Sixth-Graders' Textbooks of Singapore, Taiwan, and the USA

Der-Ching Yang, Robert E. Reys, Li-Lin Wu

This research examined the presentation of fractions in textbooks used by fifth- and sixth-graders in Singapore, Taiwan, and the United States. The specific textbooks examined were My Pals Are Here! Maths (MPHM) in Singapore; Kung Hsung (KH) in Taiwan; and Mathematics in Context (MiC) in the United States. Results show the problems posed in MiC put more emphasis on real-life situations than KH textbooks in Taiwan and MPHM in Singapore. Designing materials that provide opportunities to connect mathematics content with applications in real life is consistent with recommendations from professional organizations (Mullis et al., 1997; National Council of Teachers of Mathematics [NCTM], 2000; Organization for Economic Co-operation and Development [OECD], 2004). The activities in KH and MPHM tended to emphasize procedures, while the activities of MiC focused more on conceptual understanding, and less on the development of procedures. An examination of the mathematics textbooks revealed that MPHM introduced and developed fractions the earliest among the three countries investigated, and the content taught in MPHM was about one grade earlier than when the same content was experienced by students in KH and MiC.

Influence of Scholarships on STEM Teachers: Cluster Analysis and Characteristics

Pey-Yan Liou, Christopher David Desjardins, Frances Lawrenz

Science, technology, engineering, and mathematics (STEM) teachers' perceptions about the influence of scholarship on their decision to teach and to teach in a high-needs school were examined using cluster analysis. Three hundred and four STEM scholars, who were currently teaching, and who received funding from 45 institutions located throughout the United States responded to this national survey that was part of a larger cross-sectional program evaluation. Three disparate clusters were identified: Less committed to becoming a teacher and teaching in a high-needs school, highly committed to becoming a teacher but not to teaching in a high-needs school, and highly committed to becoming a teacher and teaching in a high-needs school. Furthermore, the results indicated that the recipient's race and the time when the scholar learned about the scholarship were related to cluster membership. These results can be used to target STEM majors who may be influenced by scholarships to enter teaching and to teach in high-needs schools.

The Cumulative and Residual Impact of a Systemic Reform Program on Teacher Change and Student Learning of Science

Carla C. Johnson, Jamison Fargo, Jane Butler Kahle

This longitudinal, five-year study of teachers and students who had participated in a systemic reform program in science explored if (1) teacher change in practice realized during a three-year program is sustained one, two, and three years following the program, (2) student performance on state science assessments two years following studying with teachers at this school still demonstrated significant differences from students who attended the control school, and (3) student performance continued to be enhanced for both white and minority students. Student achievement was assessed using the Discovery Inquiry Test in Science during sixth through eighth grades and the Ohio Graduation Test was used in 10th grade. The same students completed the test in grades 6-8 andin 10th grade. Students from the Program school

significantly outperformed students who attended the controlschool on the 10th grade state assessment in science. Findings in this study revealed the ability for sustained, whole-school, professional development programs to have a cumulative and residual impact on teacher change and student learning of science.

Student Initiatives in Urban Elementary Science Classrooms

Scott Lewis, Okhee Lee, Alexandra Santau, Neporcha Cone

Student initiatives play an important role in inquiry-based science with all students, including English language learning (ELL) students. This study examined initiatives that elementary students made as they participated in an intervention to promote science learning and English language development over a three-year period. In addition, the study examined whether student initiatives were related to other domains of classroom practices. The study involved 70 third-, fourth-, and fifth-grade classrooms with ELL students in six urban elementary schools. Results indicated that students generally made few, low-quality initiatives. Student initiatives were generally not related to the other domains of classroom practices for grades 3 and 4, whereas initiatives were significantly related to almost all the other domains for grade 5. These results contribute to the knowledge base for fostering ELL students' initiatives in science classrooms.

Zhixia You
University of Nevada, Reno

Gender Differences in Mathematics Learning

Gender differences in mathematics and science have received substantial attention in the education research since the early 1980s when strong evidence for a male advantage was found in various studies (e.g., Benbow & Stanley, 1980; Halpern, 1986; Hyde, Fennema, & Lamon, 1990; Reis & Park, 2001). Given that mathematics is required for a variety of careers, the potential cause(s) of this disparity have generated much research, much of it conflicting with other research in regard to the nature of this difference as well as the timing of its occurrence.

To examine how gender differences are related to mathematics learning, males and females have been compared using variables including innate ability, attitude, motivation, interest, and performance behaviors (Goodchild, & Grevholm, 2007; Hargreaves, Homer, & Swinnerton, 2008; Neuville & Croizet, 2007; Pekrun, Goetz, & Frenzel, 2005). Some researchers believed that male-female differences in mathematics were due to biological differences in girls' and boys' brains as perceived by the observation that girls are in general better with language and writing, and boys are better at math due to better spatial abilities (Geary, Saults, Liu, & Hoard, 2000; Halpern, 1992; Royer, Rath, Tronsky, & Marchant, 2002; Sommers, 2000; Tartre & Fennema, 1991). This implies that gender differences in mathematics may not be changeable. On the other hand, other studies have documented that gender plays no role whether girls or boys are better at math (Weaver-Hightower, 2003), and in the long run, females can be successful in math-related fields. In addition, cultural and social reasons for the underrepresentation of woman in math fields have been proposed. For example, Hedges and Nowell (1995) pointed out that gender differences in mathematics were solely the result of the different ways that male and female students have been socialized.

While differences have been observed between mathematics performance and gender, a number of questions have been raised, such as the age at which the differences occur and whether the differences change over time. Research studies have found that gender differences in mathematics occurred during elementary school years (Brandon, Newton, & Hammond, 1985; Geary, 1994), even as early as the first grade (Eccles, Adler, & Meece, 1984). Other studies pointed out that gender differences were observed in junior high school (e.g., Benbow, 1988) and high school (Leahey & Guo, 2001). In high school, the gender gap favoring males was found more common, especially in the areas of problem solving and applications. However, it is reported that such differences are minor and the gender differences may also diminish over time (Kimball, 1989).

Recent findings from both international and national studies suggest that gender differences in mathematics have declined over the years. Results from large international comparative studies such as the Trends in International Mathematics and Science Study indicate that the differences between countries are much greater than the differences between girls and boys (Mullis, Martin, Gonzalez, & Chrostowski, 2004). The latter are often not statistically significant and attend to very small differences and effect sizes. The 2005 National Assessment of Educational Progress (NEAP) data also revealed that girls lag behind boys by only three points (Geist & King, 2008). Moreover, recent works (Dwyer & Johnson, 1997; Entwisle, Alexander, & Olson, 1997; Kenney-Benson, Patrick, Pomerantz, & Ryan, 2006) showed that girls were consistently receiving better grades than boys in the classrooms due to girls' less disruptive classroom behavior and holding mastery over performance goals over time.

Presumably, the declining gap cannot be explained by genetic factors as the genes of males and females have not been differentially affected over this period. The current educational environment, in which females are expected to perform equally well as males (National Council of Teachers of Mathematics, 2000), may play an important role in the diminished gender differences. Some educators were introduced to female-friendly teaching techniques in order to

encourage and assist females in pursuing the study of mathematics and science (Ding, Song, & Richardson, 2007). It is expected there will be converging evidence to show that there may no longer be a gender gap in mathematics performance.

Boys and girls are different and as a result, we can expect that a difference exists in the way they learn (Geist & King, 2008). For example, Orhun (2007) investigated the relationship between gender and learning style. The results indicated that there were differences among learning modes preferred by female and male students. The study found that female students preferred the Convergent learning style. Convergent dominant learning abilities use abstract conceptualization and active experimentation. Learners with this learning style prefer discovery-type inquiry. Male students in this study mostly preferred the Assimilator learning style. Assimilators' dominant learning abilities use abstract conceptualization and reflection observation. They learn by watching and thinking.

Taken together, this research brief does not seek to identify that one category of students is superior to another; rather, it is to provoke more exploration of how females and males learn differently. Knowledge of how they are different in terms of mathematics and science learning can be of great value in seeking and finding ways to enhance teaching and learning for all.

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Comparing the Development of Fractions in the Fifth- and Sixth-Graders' Textbooks of Singapore, Taiwan, and the USA

Der-Ching Yang
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This research examined the presentation of fractions in textbooks used by fifth and sixth graders in Singapore, Taiwan, and the United States. The specific textbooks examined were My Pals Are Here! Maths *(MPHM) in Singapore;* Kung Hsung *(KH) in Taiwan; and* Mathematics in Context *(MiC) in the USA. Results show the problems posed in MiC put more emphasis on real-life situations than KH textbooks in Taiwan and MPHM in Singapore. Designing materials that provide opportunities to connect mathematics content with applications in real life is consistent with recommendations from professional organizations. The activities in KH and MPHM tended to emphasize procedures, while the activities of MiC focused more on conceptual understanding and less on the development of procedures. An examination of the mathematics textbooks revealed that MPHM introduced and developed fractions the earliest among the three countries investigated and the content taught in MPHM was about one grade earlier than when the same content was experienced by students in KH and MiC.*

Mathematics textbooks vary greatly across countries in their development as well as the final product (Schmidt, 2004). For example, elementary textbooks in the United States often exceed 800 pages for a single grade, whereas textbooks in Japan and Taiwan are less than one-fourth that size for the same grade level (Reys, Reys, & Chavez, 2004). This extreme variability of size raises questions about the extent to which these textbooks differ in when and how common mathematical topics are developed.

Mathematics textbooks have a powerful influence on what is learned and how it is learned (Ball & Cohen, 1996; Chavez, 2003; Mullis, Martin, Beaton, Gonzalez, Kelly, & Smith, 1997; Organization for Economic Co-operation and Development [OECD], 2004; Patrick et al., 2004; Stein, Remillard, & Smith, 2007; Tarr, Chavez, Reys, & Reys, 2006). While textbooks vary greatly in some countries, they vary less greatly in other countries where a national textbook is used, or where textbooks must conform to specific governmental regulations. Hiebert et al. (2003) and Stigler and Hiebert (2004) argue that people can learn about the advantages and disadvantages of the textbooks of their own country through international comparative studies. This research of textbooks from three different countries was done in the spirit of analyzing their textbook differences in hopes that it would be helpful to others interested in the future reformation and development of textbooks.

Theoretical Framework

Learning and understanding the concepts of fractions is an integral part of school mathematics. A meaningful understanding of fraction concepts and computational fluency with fractions provides an essential foundation for the study of advanced mathematics. Many researchers believe that if children do not have a firm and correct concept of fractions, then their ability to learn other related mathematical concepts is severely restricted (Behr, Wachsmuth, Post, & Lesh, 1984; Cramer, Post, & delMas, 2002). The importance of computational fluency and understanding of fractions as a prerequisite for success in algebra was recently highlighted in the United States (National Mathematics Advisory Panel, 2008). While computational fluency may be promoted via principles of behavioral psychology, specifically practice, knowledge of procedures is no guarantee of meaningful

understanding (Yang, Reys, & Reys, 2009; Yoshikawa, 1994). Some have argued that mathematical learning activities embedded in a context that is closely connected to daily life will not only enhance mathematical understanding but will provide anchors that will facilitate the recall and application of algorithms (Brown, Collins, & Dugid, 1989; Cooper & Harries, 2003). In fact, much of the work in the Freudenthal Institute in the Netherlands is based on the power and importance of situating mathematical learning in authentic contexts (Freudenthal, 1973).

This research was designed to carefully examine the attention that three elementary mathematics textbooks for fifth and sixth graders gave to the development of fractions. In short, the purposes of this study are:

1. To compare the differences (contexts and non-contexts) of the presentation of "fraction materials" for the fifth and sixth grade among the textbooks of *My Pals Are Here! Maths* (MPHM) in Singapore; *Kung Hsung* (KH) in Taiwan; and *Mathematics in Context* (MiC) in the United States;
2. To examine the differences in emphasis given to the presentation of mathematical knowledge (conceptual and procedural) about fractions; and
3. To examine the developmental trajectory of fractions across grade among the textbooks in the three countries.

Background

Mathematics textbooks are constantly being changed and updated. These changes are driven by different forces in different countries. For example, in Singapore and Taiwan, their national mathematics curriculum is revised periodically by their Ministry of Education, and new textbooks are developed to align with the latest national course of study. For example, Singapore proposed new mathematics curriculum standards that highlight the ability in problem solving (Ministry of Education in Singapore, 2001). The new mathematics curriculum standards in Taiwan (Ministry of Education in Taiwan, 2000) called for textbooks to connect daily-life situations and problem-solving ability. On the other hand, the United States has no national mathematics curriculum. While their mathematics textbooks are influenced by recommendations by professional organizations (National Council of Teachers of Mathematics [NCTM], 1989, 2000), the power of these recommendations varies greatly among states. Textbooks in the United States undergo continuous development and are updated constantly to meet the array of state standards as well as the adoption cycles of states and school districts throughout the country (Reys & Reys, 2006).

In Singapore and Taiwan, five different mathematics textbook series are published and marketed respectively in these countries. In order to be marketed, these textbooks were reviewed to ensure that they met the standards put forth by the Ministry of Education. Once approved, they can be sold and used in schools. In the United States, there are more than 10 different mathematics textbook series available and marketed. About one-half of the states have statewide adoption committees that review textbooks and make recommendations about adoption, whereas in the rest of the states, these decisions are made locally by school districts.

Methods

Sample of Textbooks

This study is based on a content analysis of three mathematics textbooks for fifth and sixth graders. The specific textbooks examined were MPHM in Singapore, KH in Taiwan, and MiC in the United States. The textbooks selected for review from Singapore and Taiwan represent market leaders. For example, over 60% of schools in Singapore adopted the MPHM and about 40% of schools in Taiwan used the KH as the textbooks for both grades, so they are representative textbooks and widely used textbooks in Singapore and Taiwan. MiC has only a small market share in the United States, but their mathematics textbooks did address both fifth and six grades, and this series was developed in an effort to reflect the vision of mathematics advocated by the NCTM *Standards*. Furthermore, MiC was one of the middle-school mathematics textbook series that was rated highest by the American Association for the Advancement of Science (Senk & Thompson, 2003), and this series was developed in collaboration with researchers at the Freudenthal Institute (Meyer & Ludwig, 1999).

More about the Textbooks

MPHM was produced in 2001 and according to the Singapore Ministry of Education MPHM applies both concrete and abstract models to present different mathematical concepts based on the cognitive development theories, constructive viewpoints and metacognitive theories (Ministry of Education in Singapore, 2001). There are six units related to fractions in the textbooks for the grade 5, which include fractions part I, fractions part II, ratio, percentages (I), and percentage (II). There are three units related to

fractions in the textbooks of grade 6, which includeratio, percentage, and more challenging word problems.

The KH followed the directions of the Guideline of 9-year-Integrated Mathematics Curriculum Standards (Ministry of Education in Taiwan, 2000) and emphasizes connections between real-life situations and mathematics. There are two units related to fractions in the fifth grade, which are fractions and equivalent fractions. There are six units in the sixth-grade textbook, which include the adding and subtracting of fractions, the multiplication of fractions, ratio, the division of fractions, rates, percentage and direct ratio, and four fundamental operations with fractions.

MiC was developed at the University of Wisconsin-Madison and the Freudenthal Institute at the University of Utrecht with support from the National Science Foundation (Romberg & de Lange, 1998). MiC is based on the ideas of authentic mathematics and uses real-world contexts to initiate and support mathematics being learned. The materials related to fractions in MiC include four units in fifth grade: Some of the Parts, Measure for Measure, Per Sense, and Grasping Sizes. There are three units in sixth grade: Fraction Times, More or Less, and Ratios & Rates.

Data Analysis

The researchers counted the problems, exercises, and questions posed in the student textbooks and reported the result as the total number of items. For example, consider this direction line and exercises:

> Example 1: Please calculate and find the answer for the following problems:
>
> $$1.\frac{1}{3}\times 21 \quad 2.\frac{3}{4}\times 19 \quad 3.\frac{3}{8}\times 12$$
>
> (From *Kang Hsuan 5A* [p. 32] by Kang Hsuan Educational Publishing Group, 2004a).

The textbooks contained different styles and formats. In order to answer purpose 1, we examined the items posed in the student textbooks and coded them as context or noncontext. This study analyzed the style of problems posed in the student textbooks based on the definition of Hiebert et al. (2003) that mathematical problems can be presented to students within a real-life context (Context) or by using only mathematical language with written symbols (Noncontext).

Here are examples of real-life context (Context) problems in the textbooks:

> Example 1: Carol is a customer at Save Supermarket. She wants to buy $1\frac{1}{2}$ kilograms of small Red Delicious apples. What will $1\frac{1}{2}$ kilograms of apples cost if they are priced at $1.20 per kilogram? (From *Mathematics in Context: More or Less*).
>
> Example 2: On Sunday morning, eight hundred people visit the zoo, and 75% of them are children. How many children do you think visit the zoo on Sunday morning? (From *Maths 5B*, Fong, Ramakrishnan, & Gan, 2005b).

Here are examples of Non-context exercises in the textbooks:

> Example 1: $\frac{3}{4}\times 12 = (\ )$
>
> Example 2: $\frac{4}{5} = \frac{(\ )}{100}$ or $\frac{5}{16} = \frac{25}{(\ )}$
>
> (From *Kang Hsuan 5B*, Kang Hsuan Educational Publishing Group, 2004b)

In order to answer purpose 2, we examined items in the student textbooks and classified them as focusing on procedural knowledge or conceptual knowledge (Hiebert et al., 2003). The classification depended on whether the items in the lessons helped students develop concepts mainly through procedural or contextual representations. For example, this item was coded as contextual:

> Example 1: Enrique Caston has assigned to write an article on fruit drinks for the 'Consumer' section of the newspaper. His research indicates that the amount of real fruit in fruit drinks varies. For example, he finds that the amounts of apple juice in the drinks Burst-o-Apple and Apple Fizz are rather small. Burst-o-Apple is $\frac{1}{4}$ apple juice, and Apple Fizz is $\frac{3}{10}$ apple juice. Make two bars with the same number of segments to show the amounts of apple juice? (From *Mathematics in Context: Fraction Times*)

However, if the textbooks focused on children's computational skills, the item was coded as procedural knowledge. For example:

Example 1: $7\frac{1}{2}-2\frac{3}{8}-3\frac{2}{3}$

Example 2: "Joe bakes 48 chocolate balls for selling and he sells $\frac{2}{3}$ of them. How many balls did Joe sell? And how many chocolate balls does Joe have left afterwards?" The explanation in the textbook is $\frac{2}{3}\times 48=\frac{2\times 48}{3}=32$, $48-32=16$.

(From *Maths 5A* [p.107], Fong, Ramakrishnan, & Gan, 2005a)

The data analysis included (1) counting the numbers of items related to fraction units (fraction, percentage, and ration/rate) for the fifth and sixth graders in each of the textbook series; and analyzing and coding of items in context or noncontext; (2) analyzing and coding the methods used in the items as procedural or conceptual knowledge; and (3) examining the developmental trajectory of fractions across grades among the textbooks.

Reliability and Validity

Three mathematics educators served as the raters for checking the coding reliability. These mathematics educators reviewed the methods used for coding the content in the student textbooks and then independently coded the material. This study applied the measures recommended by Wang (1996) and obtained a P value of mutual agreement of 0.766, and a value of reliability of 0.908. The average mutual agreements among the three raters are 0.700, 0.780, and 0.818 for all three textbooks, respectively. The P value and reliability were calculated by the following methods:

(1) Mutual agreement for two raters (P_i):

$$P_i\frac{M}{N_1+N_2}$$

M represents the total item numbers for mutual agreement

N_1+N_2 represents the total item numbers for coding

(2) The average P value for mutual agreement (P)

$$P=\frac{\sum_{i=1}^{n}P_i}{N}$$

N represents the total number of raters

(3) Reliability I

$$R=\frac{nP}{1+[(n-1)P]}$$

n represents the total number of raters.

Results

Table 1 reports the results of items in grades five and six that were coded as context or noncontext for the three versions. Over 95% of the MiC items were coded as context compared with slightly over half (55%) for KH and slightly under half (48%) for MPHM. Table 2 shows the percent of items coded as context varied little among the categories of fractions, ratio, and percentage for MiC (ranging from 92% to 97%). Items coded as context ranged greatly among these categories for both KH (47% to 73%) and MPHM (35% to 79%). In all three textbook series, items involving ratio were most likely to be embedded in a context.

The MiC claims to guide the children to learn mathematical knowledge through a story that happened or could happen in real-life situations. This analysis confirmed that MiC did indeed provide an overwhelming majority of their learning activities (over 95%) situated in a context.

The current tendency of mathematics education for the twenty-first century is to put more emphasis on the learning of mathematics through real-life situations. The proportions of authentic activities embedded in contexts in KH (48%) and MPHM (55%) were low when compared with the MiC (96%). In fact, several studies (Freiman & Volkov, 2004; Hiebert et al., 2003; Lesh & Lamon 1992; Mullis et al., 1997; Romberg & de Lange, 1998) indicated that there is a high relationship between mathematics learning through contexts and students' mathematical achievement. This research shows that textbooks differed greatly in the emphasis given to providing a context to connect the mathematical topics with real-life situations. Although a direct connection to real-life situations to achievement was not made in this study, recent research shows that mathematics curriculum, such as MiC, does positively impact student performance (Post et al., 2008; Tarr et al., 2008).

Table 2 summarizes the analysis of the distribution of conceptual and procedural items for the three versions. Table 2 shows that over three-fourths of the MiC items were coded as conceptual, compared with about

Table 1
The Presented Types of Context and Non-context for the Three Versions

Contents\Version	MiC	MPHM	KH
Fractions	244 (92.4%)[a]	73 (35.3%)	116 (52.7%)
	20 (7.6%)[b]	134 (64.7%)	104 (47.3%)
	264 (100%)[c]	207 (100%)	220 (100%)
Ratio/Rate	229 (100%)	124 (79.5%)	32 (72.7%)
	0 (0%)	32 (20.5%)	12 (27.3%)
	229 (100%)	156 (100%)	44 (100%)
Percentage	146 (97.3%)	70 (36.6%)	16 (47.1%)
	4 (2.7%)	121 (63.3%)	18 (52.9%)
	150 (100%)	191 (100%)	24 (100%)
Total	619 (96.3%)	267 (48.2%)	164 (55.0%)
	24 (3.7%)	287 (51.8%)	134 (45.0%)
	643 (100%)	554 (100%)	298 (100%)

Note. [a], [b], and [c] represent the number of context problems, the number of non-context problems, and the number of problems in total. The numbers in ( ) represent the percentage.

Table 2
The Summary of Conceptual and Procedural Knowledge for the Three Versions

Contents\Version	MiC	MPHM	KH
Fractions	41 (15.5%)[a]	164 (79.2%)	140 (63.6%)
	223 (84.5%)[b]	43 (20.8%)	80 (36.4%)
	264 (100%)[c]	207 (100%)	220 (100%)
Ratio/Rate	69 (30.1%)	81 (51.9%)	20 (45.5%)
	160 (69.9%)	75 (48.1%)	24 (54.5%)
	229 (100%)	156 (100%)	44 (100%)
Percentage	42 (28.0%)	141 (73.8%)	24 (70.6%)
	108 (72.0%)	50 (26.2%)	10 (29.4%)
	150 (100%)	191 (100%)	34 (100%)
Total	152 (23.6%)	386 (69.7%)	184 (61.7%)
	491 (76.4%)	168 (30.3%)	114 (38.3%)
	643 (100%)	554 (100%)	298 (100%)

Note. [a], [b], and [c] represent the number of procedural knowledge, the number of conceptual knowledge, and the number of problems in total. The numbers in ( ) represent the percentage.

Table 3
Summary of Units Distributed in Fifth and Sixth Grades for the Three Versions

Contents\Version	MiC	MPHM	KH
Fractions			
5th	122 (19.0%)	207 (37.4%)	46 (15.4%)
6th	203 (31.6%)	0 (0%)	174 (58.4%)
Percentage			
5th	89 (13.8%)	117 (21.1%)	0 (0%)
6th	0 (0%)	74 (13.4%)	44 (14.8%)
Ratio/Rate			
5th	127 (19.7%)	102 (18.4%)	0 (0%)
6th	102 (15.9%)	54 (9.7%)	34 (11.4%)
Total	643	554	298

38% for KH and 30% for MPHM. The data indicate that the MiC emphasizes conceptual knowledge while the KH and MPHM were more focused on procedural knowledge.

Table 3 summarizes the subtotal number of items distributed in the Fractions, Percentage, and Ratio/Rate of the fifth and sixth grade for the three textbook series compared with the total number of items in the Fraction units (fraction, percentage, and ratio/rate). Based on the analysis of the items related to fractions, there are about 50% of MiC, 36% of MPHM, and 74% of KH focused on the topic of fractions for fifth- and sixth-grade textbooks. A closer examination shows that in MPHM, all of the fraction units are in fifth grade, whereas in MiC and KH, the units are distributed across fifth and sixth grades with the most attention to fractions found in the sixth grade.

Table 3 documents that different attention to percentage occurred among these textbooks. For example, MiC addresses percentages only in fifth grade, while units dealing with percentage were found only in sixth grade in KH. In contrast, MPHM has units on percentage in both fifth and sixth grades.

An examination of units related to ratio/rate shows a similar lack of agreement. Table 3 reports 35.6% of ratio/rate units in MiC, 28.1% in MPHM, and only 11.4% in KH for both fifth and sixth graders' textbooks. The KH textbook did not include any units related to ratio/rate in fifth grade.

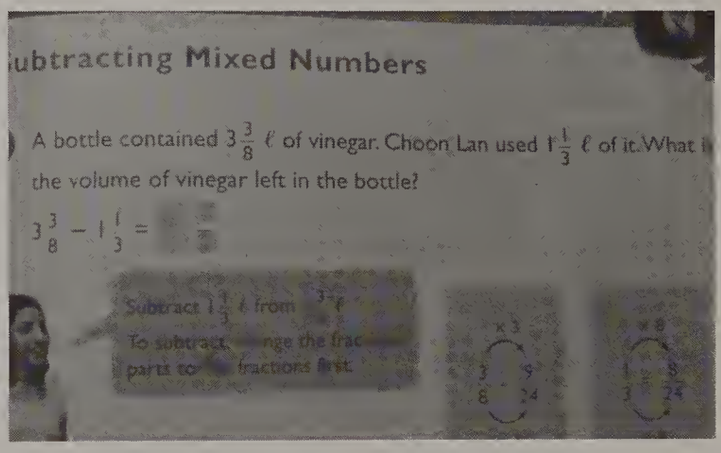
ubtracting Mixed Numbers
A bottle contained $3\frac{3}{8}$ ℓ of vinegar. Choon Lan used $1\frac{1}{3}$ ℓ of it. What
the volume of vinegar left in the bottle?
$3\frac{3}{8} - 1\frac{1}{3} =$

Figure 1. The example taught at fifth grade in MPHM of Singapore (Fong, Ramakrishnan, & Gan, 2005a, 2005b).

This research shows that MPHM not only completes the teaching of fraction in fifth grade, but also has the main focus on the teaching of percentage and ratio/rate units in the sixth grade. As a result, the proportion of the percentage units is much higher than the other two versions. This reflects an acceleration of the mathematical topics of fraction, percentage, and ratio/rate in the MPHM that places it about one grade earlier than KH.

An examination of specific pages from these textbooks shows more clearly how and when subtraction of fractions is developed. For example, Figure 1 shows one example from fifth grade in MPHM. (A bottle

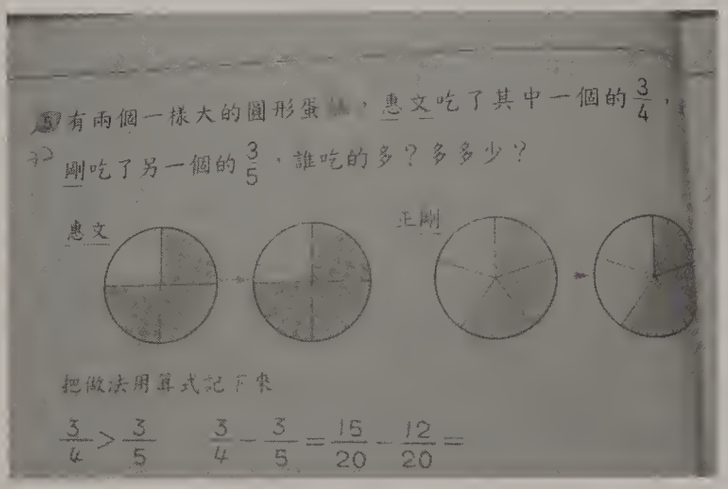

Figure 2. The example taught at sixth grade in KH of Taiwan (Kang Hsuan Educational Publishing Group, 2004a, 2004b).

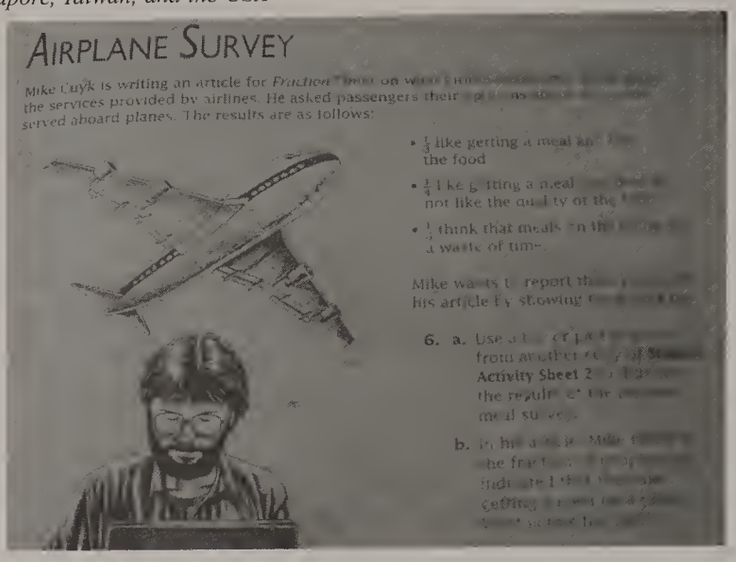
AIRPLANE SURVEY
Mike Cuyk is writing an article for *Fraction*
the services provided by airlines. He asked passengers their
served aboard planes. The results are as follows:
• $\frac{1}{3}$ like getting a meal
the food
• $\frac{1}{4}$ like getting a meal
not like the quality of the
• $\frac{1}{6}$ think that meals
a waste of time
Mike wants to report
his article by showing
6. a. Use
from another
Activity Sheet 2
the results
meal so
b. In his article, Mike
the fraction
indicate that
getting

Figure 3. The example taught at sixth grade in MiC of the United States (Holt, Reinhart, & Winston, 2003).

contained $3\frac{3}{8}$ liters of vinegar. Lan used $1\frac{1}{3}$ liters of it. What is the volume of vinegar left in the bottle? Answer: $3\frac{3}{8} - 1\frac{1}{3} = ?$).

This problem involves subtracting mixed fractions with different denominators, suggesting that their computational proficiency with fractions is well advanced. On the other hand, Figure 2 shows an example of an activity from a sixth-grade KH textbook. (There are two cakes with the same size. Weiwun ate $\frac{3}{4}$ of a cake and Tun ate $\frac{3}{5}$ of the other cake. Who ate more? How much is the difference?) Figure 2 requires subtracting fractions with different denominators. Figure 3 shows an activity that involves comparing the size of fractions ($\frac{1}{3}$, $\frac{1}{4}$, and $\frac{1}{6}$) and was taught at sixth grade in MiC. Comparing fractions precedes any operations with fractions. These examples document the lack of grade-level agreement among these three textbooks as to when computation with fractions should be developed.

Conclusion

This research reports the results of a review of mathematics textbooks that are used in three different countries, Singapore, Taiwan, and the United States. Although limited to 3 textbook series in three different countries, the data provide some important and interesting findings.

There were several differences among these textbooks. One difference was the extent to which context was provided to situate the mathematics being developed. Another difference was the emphasis given to conceptual and procedural activities. A third difference was the attention given to the topics of fractions, ratio and percentage across these grades. Here is a brief discussion of each of these differences.

The design of MiC put more emphasis on authentic mathematics as the development of fractions, ratio, and percentage was nearly always embedded in a context. While the KH textbooks in Taiwan and MPHM in Singapore sometimes provided a real-world context for the mathematics, it happened much less consistently than MiC. Whether to provide authentic contexts to situate the mathematics is a design decision that authors and publishers made as textbooks are being developed. There is certainly evidence that mathematics activities should be connected with daily-life situation (Lesh & Lamon, 1992; Ministry of Education in Taiwan, 2000; Mullis et al., 1997; NCTM, 2000; OECD, 2004). In addition, the results of several studies (Brown et al., 1989; Cooper & Harries, 2003; Post et al., 2008; Tarr et al., 2008) suggest that integrating authentic mathematics activities into teaching not only can promote the discussion and the desire to learn, but also it can enhance children's achievement in mathematics and produce meaningful learning.

This research also documents that these textbooks differed greatly in their inclusion of activities providing for conceptual and procedural knowledge. The MiC textbook provided heavy emphasis on conceptual oriented activities compared to procedural (almost 3 to

1), whereas KH and MPHM focused more on procedural knowledge versus conceptual activities (about 1 to 2). The heavy attention to procedural knowledge in KH and MPHM may be an artifact of the culture in Asian countries where structure and rules are highly respected, and these values are reflected in their textbooks. This respect for rules and one right answer has been one of the reasons offered for why many Asian students do poorly on problems involving computational estimation, where procedural rules often are inappropriate (Verschaffel, Greer, & De Corte, 2007; Yang & Li, 2008; Yang et al., 2009; Yoshikawa, 1994). Much discussion has been made about what constitutes a good balance of conceptual versus procedural activities (Hiebert & Lefevre, 1986). Once again the balance of procedural and conceptual activities is a design decision that reflects the values of the authors and publishers of the materials.

The difference among the textbooks with regard to when fractions, ratio, and percentages are treated in grades five and six was dramatic. In sixth grade, MiC students were asked to compare three fractions (Figure 3); while in sixth grade, KH students were asked to find the difference between two proper fractions (Figure 2). Yet in fifth grade, MPHM students subtract two mixed numbers (Figure 1). This research is consistent with the wide range of grade-level expectations reported among state standards in the United States (Reys, 2006). That research reported that an examination of when fractions were introduced and developed ranged from primary grades to junior high school. Decisions as to what topics to develop at what grade levels are also made by authors and publishers, but in the United States. are influenced by state standards. In the case of Singapore and Taiwan, these grade levels are determined by the recommendations from their Ministry of Education as the course of study for mathematics in their country is produced. It would be interesting to learn with more clarity what factors resulted in the grade placement of these topics in each of these textbooks.

Here are some fundamental problems related to design of mathematics curriculum that are stimulated by this study:

- How much of the mathematical content in textbooks should be situated in a real-world context?
- Is it easier or more difficult for teachers to identify the significant mathematical concepts when the mathematics content is situated in a real-world context?
- What is a reasonable balance of development that attends to both conceptual and procedural development? Should this be significantly difference across different countries? For different learning styles?
- Are students in Singapore genetically more gifted than students in Taiwan and the United States, and therefore ready to learn mathematics earlier?
- Is the goal of mathematics programs to teach more mathematics earlier?
- Is research about what, when and how children learn driving the decisions about what mathematics should be developed in specific grade levels?

There is great interest in mathematics education in learning what is happening in other countries (Chern, Shann, Horng, & Yuan, 2005; Hiebert et al., 2003; OECD, 2004). This study provides a focused look at how textbooks in three countries attend to fractions. Clear differences were found with respect to how the topic was addressed (embedded within or without an authentic context; and attention given to conceptual versus procedural development) as well as when (what grade) the topic was addressed. This research raises fundamental problems about what factors influenced the design decisions that were implemented by the authors and publishers to produce these textbooks. We hope others will continue this line of investigation and seek answers to some of these fundamental problems.

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Authors' Notes:

This paper is part of a research project supported by the National Science Council in Taiwan with grant number NSC 97-2511-S-415-010-MY3. Any opinions expressed are those of the authors and do not necessarily reflect the views of the National Science Council in Taiwan.

Keywords: content analysis; fraction; procedural knowledge; conceptual knowledge; fifth and sixth grade.

Influence of Scholarships on STEM Teachers: Cluster Analysis and Characteristics

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Science, technology, engineering, and mathematics (STEM) teachers' perceptions about the influence of scholarship on their decision to teach and to teach in a high-needs school were examined using cluster analysis. Three hundred and four STEM scholars, who were currently teaching, and who received funding from 45 institutions located throughout the United States responded to this national survey that was part of a larger cross-sectional program evaluation. Three disparate clusters were identified: less committed to becoming a teacher and teaching in a high-needs school, highly committed to becoming a teacher but not to teaching in a high-needs school, and highly committed to becoming a teacher and teaching in a high-needs school. Furthermore, the results indicated that the recipient's race and the time when the scholar learned about the scholarship were related to cluster membership. These results can be used to target STEM majors who may be influenced by scholarships to enter teaching and to teach in high-needs schools.

Recruiting and retaining highly qualified science, technology, mathematics, and engineering (STEM) teachers is imperative to maintaining the economic and security interests of the United States. Several reports (e.g., Kuenzi, Matthews, & Mangan, 2006; United States National Academies [USNA], 2007) have stressed that the well-being of America and America's competitive edge depend largely on STEM education. USNA examined the K-12 STEM curriculum and concluded that the key to an innovative and technological society rests in STEM fields. Additionally, growing pressure from globalization has solidified the idea that to maintain our advantage depends not only on how well we educate our children but especially on how well we educate them in mathematics and science (Glenn, 2000). This is particularly pertinent and troubling as STEM teachers are far more likely to leave the teaching profession than non-STEM teachers and talented individuals are far less likely to enter teaching (Guarino, Santibanez, & Daley, 2006; Shin, 1995).

Data from the 2007 Trends in International Mathematics and Science Study (TIMSS) rank American fourth-grade students in 11th place out of 36 nations and eighth-grade students in 9th place out of 49 nations on their average mathematics score (Mullis, Martin, & Foy, 2008). In science, the situation is very similar with TIMSS ranking American fourth-grade students in 8th place out of 36 nations and eighth-grade students in 11th place out of 49 nations on their average science score (Martin, Mullis, & Foy, 2008). This shows that if the United States wants to maintain its status as a world economic and technological leader and continue to compete with Asian countries, it is imperative that STEM educators, researchers, and the government act to narrow this achievement gap.

To narrow this gap, we must recruit and retain high-quality STEM teachers. A clear and positive link between teacher quality in STEM education and student achievement has been reported repeatedly (Goldhaber & Brewer, 1996; Jordan, Mendro, & Weerasinghe, 1997; National Research Council [NRC], 2000; Sanders & Rivers, 1996). Wayne and Youngs (2003) reviewed the relationship between teacher quality and student achievement and found that high school students in mathematics achieved at higher levels when their teachers have had more mathematics classes in college. This is corroborated by findings that show that content knowledge is continually correlated with student performance in the classroom (National Science Board, Science and Engineering Indicators, 2006). Therefore, if we want to bridge this international achievement gap in STEM fields, it is important that highly qualified teachers are sought, properly supported, and retained.

The No Child Left Behind Act of 2001 addresses this issue by mandating that schools staff classrooms with highly qualified teachers. However, individuals that excel in STEM fields are choosing to enter nonteaching careers (Guarino et al., 2006; United States Department of Education [USDE], 2002) and nearly one-quarter of all teachers that enter public school leave within the first three years (USDE, 2007).

Troublingly, STEM teachers with stronger abilities and academic backgrounds, as measured on standardized tests and the competitiveness of their undergraduate institution, are far more likely to leave teaching than others (Boyd, Lankford, Loeb, & Wyckoff, 2005; Guarino et al.). More alarmingly still, the current shortage of STEM teachers caused by switching professions, attrition from burnout and retirement, and a booming student population have resulted in many classes being taught by individuals who did not major in the subject, including 31% of all mathematics classes (Mervis, 2007). Clearly, it is not enough just to focus on recruiting talented individuals into STEM teaching careers, we must also focus on retaining these individuals.

Unfortunately, the situation is far bleaker for high-needs schools where classes are more likely to be taught by a substitute teacher (National Center for Education Statistics, 2006), or a teacher with emergency certification (Levine & Christenson, 1998) than a highly qualified teacher. These areas, often low-income urban centers or sparsely populated rural regions, have the greatest needs but the fewest qualified teachers. To confound the issue, attrition is greatly elevated in these areas in comparison with other settings (Darling-Hammond & Sykes, 2003; Henke, Chen, Geis, & Knepper, 2000; Ingersoll, 2002, 2003; National Commission on Teaching and America's Future, 2003; Smith & Ingersoll, 2004).

Studies have found that the rate of teacher attrition is often greater at schools that have a higher proportion of minority and low-income students than their more affluent counterparts (Shen, 1997) and that teachers will often transfer out of these high-needs schools to more affluent ones (Carroll, Reichardt, & Guarino, 2000) that are better performing (Hanushek, Kain, & Rivkin, 2004). Additionally, teachers, especially White teachers, are much more likely to stay in schools with higher student achievement and a higher proportion of Whites, i.e., nonhigh-needs schools (Boyd et al., 2005). Furthermore, attrition rates for women have been suggested to exceed those of men (Guarino et al., 2006). This is especially disheartening because the majority of individuals that choose to enter teaching careers are non-Hispanic Whites (Broughman & Rollefson, 2000) and women (Brookhart & Freeman, 1992; Broughman & Rollefson; Flyer & Rosen, 1997; Henke et al., 2000). Minority teachers do not experience the same level of attrition as non-Hispanic Whites (Guarino et al.) though they enter teaching at lower rates (Rong & Preissle, 1997). African-Americans, Hispanics, and Native Americans are far more likely to teach at high-needs schools (Keller, 2007) and educational benefits have been reported when minority students are taught by teachers of the same ethnicity (Clewell, Puma, & McKay, 2001; Dee, 2000). Therefore, to fully understand recruitment and attrition for STEM teachers at both affluent and high-needs schools, it is important to examine teacher characteristics.

Many strategies have been employed by federal and state agencies as well as teacher preparation institutions to combat the growing challenge of retaining these highly qualified teachers in high-needs settings (Mervis, 2007). Such strategies include financial incentives and alternative certification routes. The Department of Education's 2009 budget has allocated US$274 million to fund the Math and Science Partnership Program and Math Now Programs to entice STEM majors to enter careers in teaching (USDE, 2008).

Loan forgiveness in return for various activities such as military service, volunteering, and teaching has a long history under the National Defense Education Act (NDEA) of 1958. Under the NDEA, loans for higher education may be forgiven partially or fully if the loan recipient serves in the aforementioned capacities; such efforts are believed to assist individuals who would otherwise be unable to further their education and to attract them to careers they may not have considered. Jerald and Boser (1999) reported that 27 states have some loan forgiveness or scholarship program(s) for prospective teachers. Despite the long history of these efforts under the NDEA, little research has been done on the effects of such programs. More extensive research has been conducted on the influence of alternative certification programs on recruitment and retention (Clewell & Villegas, 2001; Liu, Johnson, & Peske, 2004; Villegas & Clewell, 1998) than on other recruitment strategies like financial incentives (Allen, 2005; Guarino et al., 2006). Further understanding the effect of financial incentives on recruitment and retention, especially as it pertains to high-needs schools, is an important and necessary step to deepening our understanding of how to best entice and keep highly qualified STEM teachers.

These diverse strategies to recruit and retain individuals often encounter a conundrum of dealing with mismatched perceptions about teaching and the reality

of teaching. Individuals entering STEM teaching careers may have unrealistic expectations as to what teaching actually entails. Individuals have cited a myriad of intrinsic, extrinsic, and altruistic reasons for entering teaching (Brookhart & Freeman, 1992). These include viewing teaching as a vocation and as a contribution to society (Guarino et al., 2006). "Highly persistent" teachers have emphasized the intrinsic and moral rewards of teaching as factors influencing their persistence to teach (Watt & Richardson, 2008). Additionally, many teachers have reported that teaching allows them more time for their family, especially career changers (Guarino et al.; Richardson & Watt, 2005). Therefore, understanding the perceptions of individuals entering a teaching career in STEM fields is imperative for reducing attrition, especially for high-needs schools and school districts where teacher attrition and turnover are quite high (Carroll & Sathya, 2008).

Attrition rates are highest during the first three years of teaching and after 25 years when teachers are leaving the profession for retirement (Grissmer & Kirby, 1997). Therefore, programs that target these first three years and ease the transition into a teaching career should help to reduce attrition rates. One such program is the National Science Foundation's Noyce Scholarship program (National Science Foundation, n.d.), a national scholarship that aims to recruit highly capable and top-performing STEM majors into the STEM teaching profession. The Noyce program does this by providing incentives that help to offset the costs of the recipients' teacher education program and STEM training but in return requires a two-year or more commitment, depending on the amount of support, to teach in a high-needs school or school district. If the recipients choose not to enter teaching or teaches in a nonhigh-needs school or school district, then they are required to pay back the loan, otherwise the loan is forgiven at the end of the commitment. The Noyce program requires a multiple-year teaching commitment that acts to combat STEM teacher attrition.

Research Question

As the research base is sparse regarding the effects of various strategies on recruitment and retention of qualified teachers in high-needs areas (Allen, 2005), the purpose of this research was to examine the influence of the Noyce scholarship on these issues, focusing on the effect of financial incentives on recruitment to teach in high-needs schools and to become teachers. The Noyce scholarship was examined instead of similar financial incentives, as data were readily available as part of a larger program evaluation. By understanding the effect of the Noyce scholarship on teachers' perceived commitment, we hoped to identify criteria that could be used by universities and governments to target for recruitment potential scholars that perceived the greatest impact of scholarship on their commitment to teach and teach at high-needs schools. Specifically, we wanted to know: do scholarship recipients have differing perceptions regarding the effect of the Noyce scholarship on their commitment to becoming science and mathematics teachers and to teach in high-needs schools? A corollary objective, if a difference was found, was to categorize the demographic characteristics and perceptions of scholarship recipients related to their differing perceptions regarding the effect of the Noyce scholarship on their decision to become science and mathematics teachers and teach in high-needs schools.

Methods

The methods section contains three subsections; a sample description section, an instrument section, and a section on the statistical techniques we employed. In the sample description section, data on the participants and the teacher preparation programs that were collected as part of the program evaluation will be presented. In the instrument section, an overview of the survey will be discussed first. Then the data for differentiating the participants' perceptions about the scholarship's influence on becoming a teacher and teaching in a high-needs school will be described. The instrument section concludes by describing the data used to differentiate the demographics and perceptions of the participants. Finally, in the statistical techniques section, the three statistical analyses that were used to answer the research problem will be described.

Sample Description

Participants were 304 former and current Noyce scholarship recipients who were currently teaching full or part-time, a subsample of all Noyce scholars that volunteered to participate with the program evaluation team. These current STEM teachers received their teacher preparation education from 45 institutions around the United States. Of the 304 scholars responding to the survey, 65.5% were female and 34.5% were male; 70.5% were White and 29.5% were non-White. The majority, 83.6%, of the participants'

highest degree was a bachelor's, 11.4% had master's, and 5.0% had doctorate's. A total of 38.5% of the participants' indicated that they intend to teach mathematics and 61.5% of the participants' indicated that they intend to not teach mathematics, that is, most of them intend to teach science. The teachers' average age at the end of 2007 was 31 years with a standard deviation of 8.6. The teachers' cumulative GPA was 3.5 with a standard deviation of 0.4. The teachers had strong content backgrounds and reported taking several mathematics and science classes within the past few years. Forty-eight percent of all teachers indicated taking 10 to 20 STEM courses and 21.6% of teachers indicated taking more than 20 STEM courses. The majority of teachers specified that they had taken one to eight teaching methods courses.

To fully understand the scholars, it is important to describe the teacher education programs which trained them to become STEM teachers in high-needs settings. The programs that received funding through the Noyce scholarship exhibited a great deal of variety both within and across institutions. The programs represent an array of both traditional and alternative certification options. These 304 STEM teachers came from 45 programs which were awarded Noyce scholarships, of which 43 (95.6%) responded to the Noyce Scholarship Program Evaluation Principal Investigator Survey (Lawrenz, Appleton, Bequette, Desjardins, Liou, Madsen et al., 2008). The survey was administered to the principal investigators (PIs) for the Noyce program at each of the participating teacher education programs. Fifty-two percent indicated the Noyce scholarship paid for over 75% of their scholars' tuition. In general, PIs indicated that Noyce funding greatly increased their ability to recruit a variety of students and that Noyce funding had a lesser effect on perceptions about teaching careers, and relationships with the community, districts, STEM faculty, and industry.

Although the implementation of Noyce varies across programs, generally programs use some screening criteria to select scholars, such as GPA (100% of all programs), personal statement (98%), letters of recommendation (93%), structured interviews (80%), upper-level undergraduate status in science or mathematics major (74%), bachelor's degree in the candidate's subject area (73%), and previous work experience (68%). The intent is to award the scholarship to the most qualified STEM candidates in terms of content knowledge and commitment to high-needs education.

To aid in future retention, the awarding programs also provide specific activities to best prepare scholarship and stipend recipients to become successful science and mathematics teachers in high-needs settings. Often this involves providing opportunities for interactions with children from different cultures such as mentoring or tutoring, coursework related to diverse cultures, and specific instruction about practicing in high-needs schools. Further experience is often provided with opportunities to observe/work on a limited basis through practicum, student teaching, and supervised actual classroom teaching in the form of an internship, all experienced in high-needs schools.

Instrument

The data utilized in this study were gathered from the Noyce Scholarship Program Evaluation Scholar Survey that was administered online during the summer of 2007. Participants were asked to respond to a variety of items regarding their perceptions of and experiences with the Noyce scholarship program. The survey was composed of six main components: project overview; program characteristics and organization; teaching environment and experience; decision to become a teacher; background and experience; and overall experience of the program. Completion of this survey was voluntary. The data from this survey were supplemented with background data collected by the Macro International Inc. (MII) survey. The MII survey was mandatory and filled out by the PIs of the Noyce programs.

For this study, we focused on eight items from the scholar survey that were related to scholars' perceptions of the Noyce scholarship's influence on becoming a teacher or teaching in a high-needs school. There were four variables of interest; two variables were formed through factor analyses on six Likert-type rating scale items and two were single categorical items. The six Likert-type items were from the "decision to become a teacher" section of the survey and these were examined to determine if an underlying factor structure existed. Participants were asked to respond to the question: "How influential is the Noyce Scholarship money in your commitment to: Become a teacher, complete the certification program, take a teaching job, teach in a high-needs school, remain teaching in a high-needs school for the full term of your commitment, and remain teaching in a high-needs school beyond the full term of your commitment?" Two factors were found among these six items through use of hierarchical cluster analysis and

Table 1
Descriptions of Two Continuous Variables, "Influence of Scholarship on Becoming a Teacher" and "Influence of Scholarship on Becoming a High-Needs School Teacher"

Factor (Cronbach's alpha)	*N* of items	Item content	Item option
"Influence of scholarship on becoming a teacher" ($\alpha = 0.88$)	3	(a) become a teacher (b) complete the certification program (c) take a teaching job	(1) not at all influential, (2) not very influential, (3) somewhat influential and (4) very influential
"Influence of scholarship on becoming a high-needs school teacher" ($\alpha = 0.90$)	3	(d) teach in a high-needs school (e) remain teaching in a high-needs school for the full term of your commitment (f) remain teaching in a high-needs school beyond the full term of your commitment	

confirmatory factor analysis. More detailed information can be found in Liou, Kirchhoff, and Lawrenz (in press). One of the factors was named "influence of scholarship on becoming a teacher" while the other was named "influence of scholarship on becoming a high-needs school teacher." The Cronbach's alphas for the two factors were 0.88 and 0.90, respectively. The information about these two factors of item content and response options is presented in Table 1.

The other two items were "Would you have become a teacher if you had not received the Noyce scholarship?" and "Would you have decided to teach in a high-needs school if you had not participated in the Noyce Scholarship Program?" Participants responded to the former item using the following ordinal scale "No, possibly, and yes"; while participants responded to the latter item using the following ordinal scale "No/I have not taught in a high-needs school, possibly, and yes."

Using the four variables above to differentiate recipients' perceptions about becoming a teacher and teaching in a high-needs school, the scholarship recipients were divided into clusters (described below in the statistical analysis section). Scholar demographic characteristics and perceptions were compared across the separate clusters to see if there was a difference among the groups. The STEM teachers' characteristics include gender, minority status, highest degree (a measure of teacher quality), intention to teach mathematics (yes indicates the intention to teach mathematics and a no indicates the intention to teach science), the average age at the end of 2007, and the average cumulative GPA. Five survey items were selected to indicate the scholar's perceptions and reasons for entering teaching. The items were "Did you first learn about the Noyce scholarship before or after you decided to become a teacher"; "In becoming a teacher, do you consider yourself a 'career changer'"; "I like the flexibility and/or autonomy of STEM teaching"; "I feel that a teaching career is conductive to my family life"; and "I feel this career allows me to 'make a difference' in the world."

All items were nominal and dichotomous, and scholars could respond either with before and after in the first item, and either yes and no for the remaining four items. These items were chosen because prior research, as described in the introduction, has shown these variables to be important variables in determining whether a STEM major enters teaching and decides to teach in a high-needs school as well as being important for retention. Furthermore, the national evaluation team identified these items as the most salient items with respect to perceptions about scholarship effects. Finally, these variables, both demographic and perception items, were limited by their availability on the program evaluation instrument.

Statistical Techniques

Two-stage hierarchical cluster analysis (TSHCA, performed with SPSS [SPSS, 2008]) was used to categorize STEM scholars' perceptions of the Noyce scholarship. TSHCA is a technique which statistically groups similar participants together. Scholars included in the same cluster are considered more closely related to each other than scholars in other clusters. In other

words, TSHCA analysis seeks to identify a set of groups which both minimizes within-group variation and maximizes between-group variation (Johnson, 1998).

After formation of the clusters, analysis of variance (ANOVA) and two-way contingency table analysis were used to examine whether there were differences among the clusters for the STEM teachers' demographic characteristics and perceptions.

Results

Three Groups from TSHCA

Four variables were included in TSHCA. Two of the four variables were the factor scores, "influence of scholarships on becoming a teacher" and "influence of scholarship on becoming a high-needs teacher." The other two variables were "Would you become a teacher if you had not received the Noyce scholarship?" and "Would you have decided to teach in a high-need school if you had not participated in the Noyce scholarship program?"

TSHCA divided the 304 STEM teachers into three clusters. Seventy-one recipients were in the first cluster, 119 were in the second cluster, 104 were in the third cluster, and 10 cases were excluded from the analysis because of missing values.

The three clusters showed clear distinctions for the four variables. Figure 1 shows that the Noyce scholarship was perceived as having relatively high impact on recipients in Cluster 1's decision to become a teacher. The confidence interval of Cluster 1 is higher and does not overlap with the confidence interval of Clusters 2 and 3, so it indicates that Noyce scholarship was perceived as having statistically significant higher impact on recipients in Cluster 1. Figure 2 shows that the scholarship was perceived as having a large impact on recipients in both Clusters 1 and 2 on their decision to become a high-needs school teacher. Figure 3 shows scholars in Clusters 2 and 3 all indicated that they would have become a teacher if they had not received the Noyce scholarship, but all scholars in Cluster 1 selected "no" or "possibly." In other words, the scholarship has impact on recipients in Cluster 1 since they may not become a teacher if they had not received the

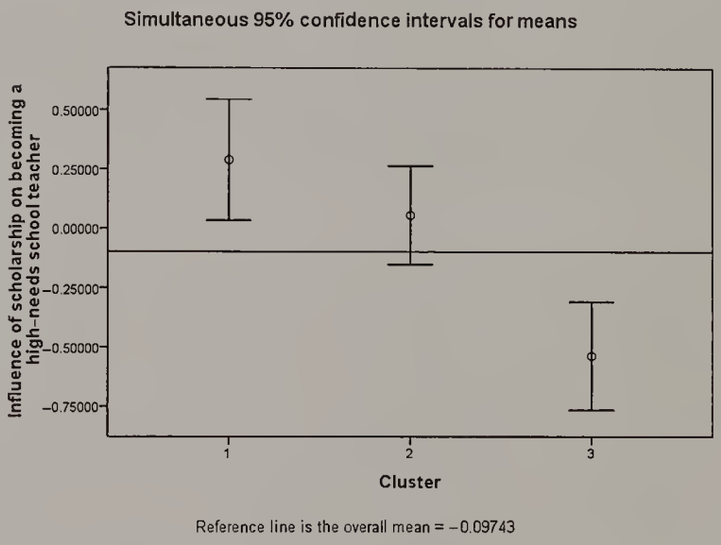

Figure 2. The within-cluster percentage plot of the factor "influence of scholarship on becoming a high-needs schools teacher."

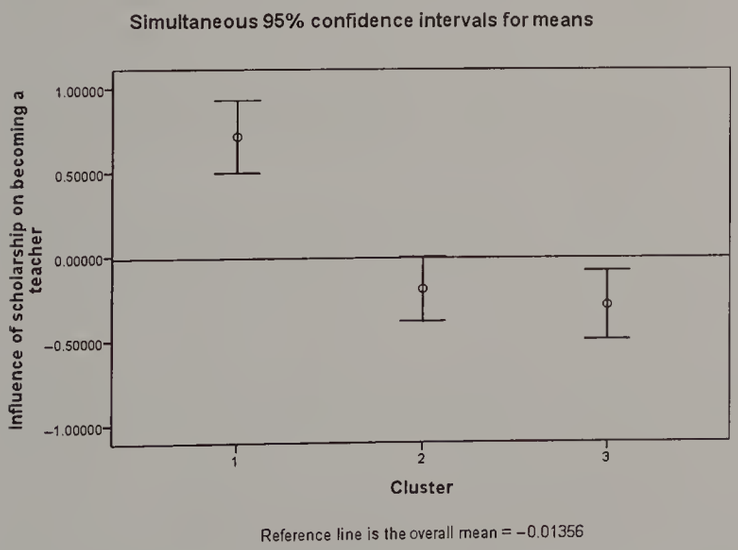

Figure 1. The within-cluster percentage plot of the factor "influence of scholarship on becoming a teacher."

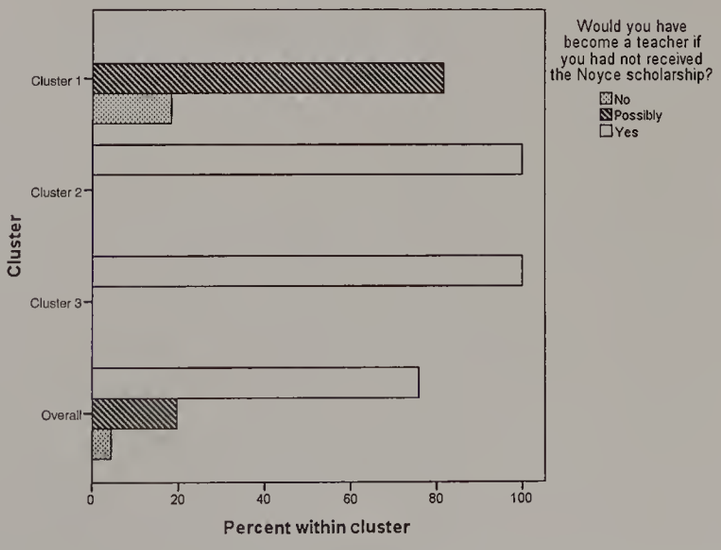

Figure 3. The within-cluster percentage plot of the item "would you have become a teacher if you had not received the Noyce scholarship?"

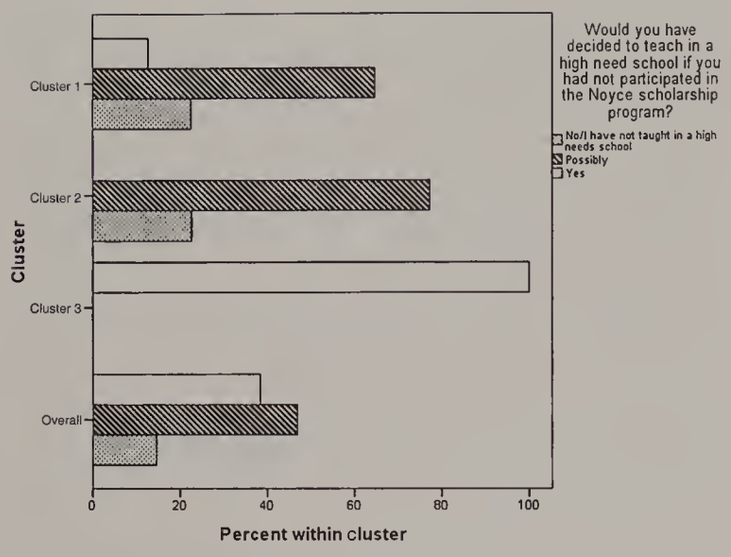

Figure 4. The within-cluster percentage plot of the item "would you have decided to teach in a high-needs school if you had not participated in the Noyce scholarship program?"

Noyce scholarship. Figure 4 shows scholars in Cluster 3 all indicated they would have decided to teach in a high-needs school if they had not participated in the Noyce scholarship program, but scholars in Clusters 1 and 2 indicated that "no/I have not taught in a high-needs school" or "possibly" when asked whether they would teach in a high-needs school.

There were significant main effects of cluster on each continuous variable included in the clustering algorithm for "influence of scholarship on becoming a teacher," ($F(2,293) = 35.82$, $p < 0.01$) and for "influence of scholarship on becoming a high-needs school teacher" ($F(2,293) = 19.47$, $p < 0.01$). These statistical tests showed that the three clusters had different means for these two variables. There is no statistical test for the two categorical variables, so a visual examination of Figures 3 and 4 was performed to further explain the clustering. Cluster 1 contained 71 teachers who gave highest ratings for the two continuous variables and only "no" and "possibly" ratings for the two categorical variables. We named this cluster the "less committed to becoming a teacher and teaching in a high-needs school." Cluster 2 contained 119 teachers whose responses for the two continuous variables were lower than Cluster 1, and their responses for the categorical variable "Would you have become a teacher if you had not received the Noyce Scholarship?" were all "yes," but their responses for the categorical variable "Would you have decided to teach in a high-needs school if you had not participated in the Noyce scholarship program?" were "possibly" or "no." We named this cluster the "highly committed to becoming a teacher but not to teaching in a high-needs school." Cluster 3 contained 104 teachers and exhibited the lowest scores on the two continuous variables, and answered "yes" for the two categorical variables. We named this cluster the "highly committed to becoming a teacher and teaching in a high-needs school."

Demographic Characteristics and Perceptions for the Three Groups

Table 2 shows the descriptive statistics of scholarship recipients' demographic characteristics and perceptions for the three clusters.

Two-way contingency table analyses were conducted to evaluate the relationship between the three groups and minority status (non-White vs. White), gender (female vs. male), highest degree (bachelor's, master's, and doctorate's), intention to teach mathematics (yes vs. no), the time when they first learned about the Noyce scholarship (before vs. after), whether they viewed themselves as career changers (yes vs. no), whether they like the flexibility and/or autonomy of STEM teaching (yes vs. no), whether they feel that a teaching career is conducive to their family life (yes vs. no), and whether they feel this career allows them to "make a difference" in the world (yes vs. no). ANOVA was conducted to examine whether the means of the STEM teachers' ages and cumulative GPAs were the same among the three clusters.

For the two-way contingency table analyses, minority status and the time when these STEM teachers first learned about the Noyce scholarship were statistically significant ($\chi^2(2, N = 279) = 7.6$, $p = 0.004$). Forty-seven percent of the White STEM teachers were in the "highly committed to becoming a teacher but not to teaching in a high-needs school" cluster, while 47% of the non-White STEM teachers were in the "highly committed to becoming a teacher and teaching in a high-needs school." This result showed that more White STEM teachers have higher commitments to become teachers than to become teachers in high-needs schools and that non-White STEM teachers have high commitments to not only become teachers but also to teach in high-needs schools. The relationship between the three clusters and the time when they first learned about the Noyce scholarship was also significant ($\chi^2(2, N = 294) = 20.16$, $p < 0.001$). Fifty-one percent of the STEM teachers who answered "before" (those who had heard about Noyce funding

Table 2

Cluster Composition as a Function of Demographic Characteristics and Perceptions

Demographic characteristics	Cluster 1 ($N = 71$)	Cluster 2 ($N = 119$)	Cluster 3 ($N = 104$)	Total ($N = 294$)
Race				
White	46 (23%)	91 (47%)	58 (30%)	195
Non-White	23 (27%)	22 (26%)	39 (47%)	84
				279
Gender				
Female	49 (25%)	82 (42%)	64 (33%)	195
Male	22 (22%)	37 (38%)	40 (40%)	99
				294
Highest degree				
Bachelor's	27 (24%)	44 (39%)	41 (37%)	112
Master's	4 (27%)	5 (33%)	6 (40%)	15
Doctorate's	5 (72%)	1 (14%)	1 (14%)	7
				134
Intention to teach mathematics				
Yes	22 (20%)	45 (40%)	45 (40%)	112
No	49 (27%)	74 (41%)	59 (32%)	182
				294
The average age at the end of 2007	Mean = 32.21 (SD = 1.20)	Mean = 29.83 (SD = 0.71)	Mean = 31.2 (SD = 0.82)	
				294
The average cumulative GPA	Mean = 3.53 (SD = 0.34)	Mean = 3.50 (SD = 0.34)	Mean = 3.37 (SD = 0.36)	
				160
Did you first learn about the Noyce scholarship before or after you decided to become a teacher?				
Before	22 (51%)	12 (28%)	9 (21%)	43
After	49 (19%)	107 (43%)	95 (38%)	251
				294
In entering the teacher certification program, do you consider yourself to have made a "career change"?				
Yes	44 (30%)	52 (35%)	51 (35%)	147
No	26 (19%)	63 (45%)	50 (36%)	139
				286
I like the flexibility and/or autonomy of STEM teaching				
Yes	50 (24%)	88 (41%)	75 (35%)	213
No	19 (28%)	25 (38%)	23 (34%)	67
				280
I feel that a teaching career is conducive to my family life				
Yes	47 (22%)	88 (41%)	80 (37%)	215
No	23 (33%)	26 (37%)	21 (30%)	70
				285
I feel this career allows me to "make a difference" in the world				
Yes	68 (24%)	110 (39%)	102 (37%)	280
No	2 (22%)	6 (67%)	1 (11%)	9
				289

Note. Cluster 1: Less committed to becoming a teacher and teaching in a high-needs school; Cluster 2: Highly committed to becoming a teacher but not to teaching in a high-needs school; Cluster 3: Highly committed to becoming a teacher and teaching in a high-needs school.

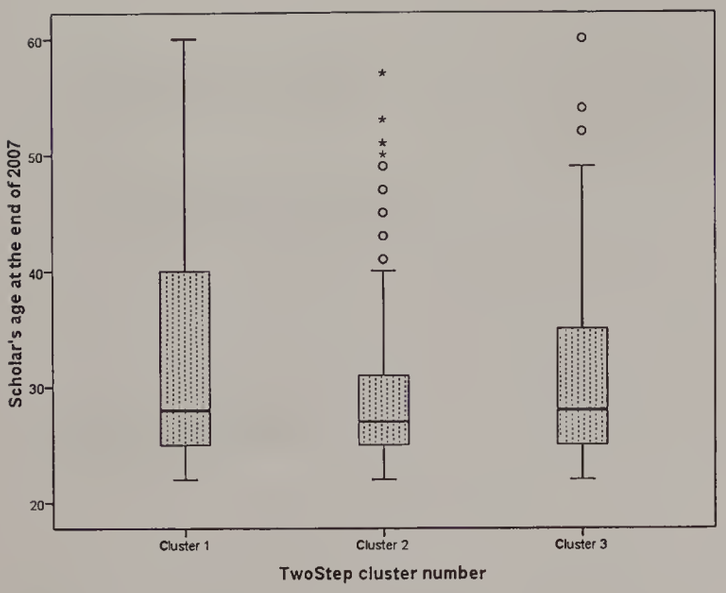

Figure 5. Age by the three clusters.

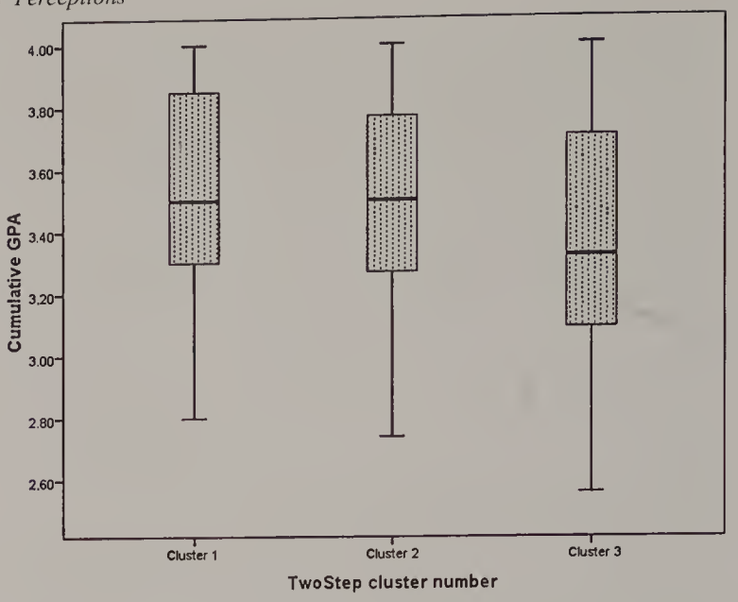

Figure 6. Cumulative GPA by the three clusters.

prior to making a decision to teach) reported that the scholarship had an effect on recruiting them, but more than half of them were in the "less committed to becoming a teacher and teaching in a high-needs school" cluster.

There was no statistical evidence to suggest there was a difference among the three clusters in gender ($\chi^2(2, N = 294) = 1.65; p = 0.44$), highest degree ($\chi^2(3, N = 134) = 7.67; p = 0.11$), intention to teach mathematics ($\chi^2(2, N = 294) = 2.71; p = 0.26$), whether STEM teachers viewed themselves as career changers ($\chi^2(2, N = 286) = 5.47; p = 0.07$), whether they like the flexibility and/or autonomy of STEM teaching ($\chi^2(2, N = 280) = 0.71; p = 0.70$), whether they feel that a teaching career is conducive to their family life ($\chi^2(2, N = 285) = 3.56; p = 0.17$), and whether they feel that a teaching career allows them to "make a difference" in the world ($\chi^2(2, N = 289) = 3.21; p = 0.20$).

As for the STEM teachers' age $F(2,291) = 1.97; p = 0.14$) and GPA $F(2,157) = 2.9; p = 0.06$), there was no statistical evidence to indicate that a difference among the three clusters existed. However, in Figure 5, it appears that teachers' age in the "less committed to becoming a teacher and teaching in a high-needs school" cluster had a wider range than the other two clusters and in Figure 6, teachers' cumulative GPA in the "highly committed to becoming a teacher and teaching in a high-needs school" had a wider range than the other two clusters.

Discussion

In this study, we identified four variables that successfully differentiated STEM scholarship recipients into three clusters. These three clusters divided the STEM teachers based on their perceptions of the influence of a national scholarship on their decision to teach and their decision to teach in high-needs schools. The importance of these variables lies in their ability to differentiate scholarship recipients into three disparate clusters that could be used by scholarship agencies for recruitment. Future scholarship research should focus on these variables to allow for a more thorough and fuller understanding of why STEM scholarship recipients form distinct groups based on these variables.

The three clusters that were differentiated in this study were: less committed to becoming a teacher and teaching in a high-needs school, highly committed to becoming a teacher but not to teaching in a high-needs school, and highly committed to becoming a teacher and teaching in a high-needs school. The STEM teachers in the less committed cluster were the most influenced by the scholarship funding and they perceived the funding to affect their decision to enter teaching and to teach at high-needs schools. The STEM teachers in the highly committed to teaching but not high-needs cluster had a perceived effect of the scholarship on their decision to teach in high-needs schools but not on their decision to enter teaching. Finally, those STEM teachers that were in the highly committed to teaching and high-needs cluster were the least influenced by the scholarship and they did not perceive an effect of the funding on their decision to enter teaching or to teach STEM classes at high-needs schools.

The scholars in these clusters differed statistically on only two of the ten demographic characteristics and

perceptions that were examined in this study. Additionally, two other characteristics, GPA and career changer classification, were close to being significant and warrant further discussion. The three clusters differed in their proportion of White and non-White recipients. White scholarship recipients were more likely to be in the highly committed to teach but not high-needs cluster indicating that White scholarship recipients were the most profoundly affected by the scholarship to teach STEM in high-needs settings. Non-White scholarship recipients were more likely to be in the highly committed to teaching and high-needs cluster indicating they perceived a lower effect of the scholarship on their decision to teach or to teach at high-needs schools. These results suggest that scholarships may be important in recruiting White STEM majors to teach at high-needs schools.

Unfortunately, research has found that White teachers tend to move away from these poor-performing schools and into more affluent and better-performing ones (Boyd, Grossman, Lankford, Loeb, & Wyckoff, 2006). However, because of the teaching commitment that scholarships, such as the Noyce scholarship require, attrition rates for White teachers may decrease as they are required to work two or more years at their schools to fulfill their contractual obligations. This obligation may be influential in getting these teachers to remain beyond the critical years of attrition (Grissmer & Kirby, 1997) and subsequently it may act to combat attrition after the contract has been completed.

Non-White scholarship recipients were already committed to STEM teaching and teaching in high-needs settings and it appears that the funding had little or no perceived impact on recruiting them. The notion that non-White teachers would be more committed to teaching in high-needs schools is in line with previous research that has found that non-White groups (e.g., African–Americans, Hispanics, and Native Americans) are more likely to teach at high-needs schools (Keller, 2007). Even though the funding may not have influenced their decision to enter teaching or teach at high-needs schools, it likely provided at least some of the recipients with the opportunity and an avenue to enter teaching by helping to support their education. Therefore, it could be reasoned that for some non-White recipients, the funding directly allowed them to teach and teach at high-needs schools by providing additional funds for college and subsequently because of this, the scholarship indirectly recruited these non-White recipients.

In this study, we treated race as White or non-White because of small within-group sample sizes. All scholars identified as non-White may not share convergent beliefs about teaching and it is likely that with a finer grained lens, certain ethnic groups might perceive an affect of the scholarship on their decision to enter teaching or to teach at high-needs schools or both. National scholarships may then still be a very important recruitment tool if these non-White recipients proved to be heterogeneous with respect to their perceptions about the effect of the funding on their decision to enter teaching. Future work teasing apart these non-White scholars is necessary to completely understand the effects.

The three clusters differed statistically regarding the time when the STEM teachers first learned about the scholarship. This may indicate that the scholarship influences the recruitment of STEM majors into a teaching career and perhaps into teaching in high-needs schools. About half of the teachers who learned about the scholarship before they decided to become a teacher were in the less committed cluster. At the same time, a comparatively high percentage of the teachers who learned about the scholarship after they decided to become a teacher were in the highly committed to teach and high-needs cluster.

These results suggest that STEM majors that had already decided to become a teacher before hearing about the funding were already highly committed to teaching and to teaching in high-needs schools and subsequently perceived no effect of the funding on their commitment to teach. The STEM majors who had not decided to become a teacher before hearing about the funding had a higher perceived effect of the funding on their commitment to teach and teach at high-needs schools.

This suggests that national scholarships could be an important tool for recruiting STEM majors, who have not already decided to become STEM teachers, into teaching and teaching at high-needs schools. For these scholarships to work, it is imperative that they be salient to STEM majors regardless of whether they have indicated an interest in teaching. These scholarships should be attractive and act to entice STEM majors into a career that many consider to be less lucrative than other potential careers. Science and mathematics departments and their respective faculty should be made aware of these types of funding opportunities so that they may encourage STEM majors uncertain of their future career plans to consider

STEM teaching careers. Increased cooperation and collaboration between these departments and the science education and mathematics education departments may help to bolster scholarship visibility to STEM majors and STEM majors already interested in teaching.

The results presented here suggest that STEM majors already interested in teaching were relatively unaffected by the funding. As may be the case with some non-White scholars, STEM majors already interested in pursuing teaching careers and teaching at high-needs schools may not have an avenue to fully support their career aspirations and these national scholarships may be vital to them by providing additional funding, allowing them to remain in college and earn degrees. In these instances, these national scholarships could be seen as a form of indirect recruitment on STEM majors. Again, this reinforces the need for these scholarships to be readily visible to STEM faculty for properly advising their students.

GPA and whether or not the scholarship recipient classified him- or herself as a career changer were both very close to being statistically significant. It is plausible that with a larger sample size and greater power that the differences among the groups on these variables would have been significant. These variables will be further discussed and explored with the caveat that the implications are speculative and are based on the assumption that a larger sample size would show significance.

STEM scholarship recipients that were in the less committed cluster had higher GPAs than the other STEM scholars in either cluster. This suggests that the top-ranking scholarship recipients had a higher perceived effect of the scholarship on their decision to enter teaching and to teach at high-needs schools. These scholars may have initially decided to apply for the scholarship not necessarily because of their interest in teaching but because they were high-ranking STEM majors and thought they would be competitive for this prestigious scholarship. Therefore, nationally prestigious scholarships may act to entice high-quality STEM majors, who have not considered a career in teaching, into the teaching profession and possibly into high-needs schools. This is extremely important as high-quality STEM majors tend to not enter teaching (Guarino et al., 2006; USDE, 2002) and especially not high-needs schools (NCES, 2006). Recruiting these top-performing STEM majors into high-needs schools is vital if we want to empower these students and bolster their academic achievement (Goldhaber & Brewer, 1996; Jordan, Mendro, & Weerasinghe, 1997; NRC, 2000; Sanders & Rivers, 1996). Because of the required commitment to teach for two or more years in a high-needs school, it seems highly likely that national scholarships that have contractual obligations to teach in a high-needs setting may also act to retain these high-quality STEM majors which is essential as these are exactly the individuals that tend to leave the profession (Boyd et al., 2005; Guarino et al.).

Regarding career changer status, the less committed cluster contained the lowest proportion of scholarship recipients that considered themselves as noncareer changers. This implies that the scholarship recipients who were less committed, those most highly influenced by funding, were not career changers. Recipients could have identified themselves as noncareer changers for two reasons: They have always been committed to teaching or they have not yet entered a position that they consider a career. It is more likely that the majority of recipients that were in the less committed cluster were in the latter case. The reason is that recipients who had already decided to become a teacher before hearing about the scholarship were more likely to be in the highly committed to teaching and high-needs cluster. Therefore, the recipients who have never held careers would form the majority of the non career changers in this cluster. This implies that recipients who have not entered a career have a perceived effect of funding on their commitment to teach and teach at high-needs schools. Presumably, these recipients were also young, if they have not held careers, indicating that funding had a great effect on their commitment to teach. Recipients who identified themselves as career changers were located at a relatively equal proportion across the clusters.

Several variables (gender, age, highest degree attained, intend to teach math, flexibility of STEM teaching, teaching is conducive to my family life, and "make a difference") were not significant. These results imply that the perceptions about the effect of funding on decisions to teach or decisions to teach in high-needs schools do not vary depending upon gender, age, scholars' highest degree, or whether they intend to teach mathematics or science. These results are surprising as prior research has identified gender (Brookhart & Freeman, 1992; Broughman & Rollefson, 2000; Flyer & Rosen, 1997; Henke et al., 2000) and teacher quality, which scholars' highest degree is a measure of (Guarino et al., 2006; USDE, 2002), as

factors affecting entry into teaching. If our results were congruent with prior research, we would have expected both men and scholars with higher degrees to be in the less committed cluster or the highly committed to teaching but not high-needs cluster. Alternately, we would have expected females and recipients with lower degrees (i.e., bachelor's) to be in the highly committed to teaching but not high-needs and highly committed to teaching and high-needs clusters.

The variables "I like the flexibility and/or autonomy of STEM teaching," "I feel that a teaching career is conducive to my family life," and "I feel this career allows me to 'make a difference' in the world," were examined as research has found these factors to be important reasons for individuals to enter teaching (Brookhart & Freeman, 1992; Guarino et al., 2006; Richardson & Watt, 2005). We would have expected recipients answering yes to these items to be overrepresented in the highly committed to teaching but not high-needs and the highly committed to teaching and high-needs clusters. However, this was not the case. This is not to suggest that these items are not important to STEM majors entering teaching or deciding to teach at high-needs schools, it just implies that the recipients in the clusters do not have significant variation in these items. In other words, variations in these items cannot be linked to perceived effects of funding on commitment to teaching.

There were several limitations of this study that require discussion. First, the data were from a cross-sectional evaluation survey and it did not employ an experimental or quasi-experimental design. Therefore, there is no evidence or basis to say causal relationships exist among the scholarship recipients' demographic characteristics and their perceptions and ultimately their assignment to one of three clusters. The only credible statements that can be made from the data are statements regarding correlations. Because this is a cross-sectional study and not a longitudinal study, we were unable to examine retention and continued satisfaction with teaching or the Noyce program. Future work examining the relationship between perceived effect of financial incentives on commitment to teach and teach at high-needs schools and recruitment is a necessary second step. We were also unable to track the scholarship recipients and see how their perceptions evolved over time (i.e., tracking their perceptions about teaching at high-needs schools in their first and consecutive years until their contractual obligations end and whether they decide to remain in teaching and remain at high-needs schools afterwards). A longitudinal study would have allowed a more thorough understanding of how these perceptions evolved into tangible decisions that teachers make when deciding to remain in teaching.

Another limitation of this study was that this research project was a subset of a program evaluation. Because of this, we were limited by the instrument and could not examine variables that might have proven to be more relevant to examining the relationship between scholarship and perceptions about teaching and recipients' demographics. For example, other items not available on our instrument that explored reasons for entering teaching could have been useful for further differentiating the clusters. Future research might use other items that more appropriately measure these constructs and ask about decision to teach as well as examining other potentially useful demographic characteristics that were unavailable in this study.

Scholars' perceptions about a scholarship's effect on their decision to teach and to teach in high-needs schools, though important, may not be the most salient factor influencing their decision to enter teaching. Furthermore, it would be prudent to examine this variable in combination with other factors. In addition, several of the variables, GPA and career changer, were close to being significant. This is likely the result of our moderate sample size. If we had a larger sample size, and subsequently higher power, these variables may have been significant. Several of our variables, notably race, had small sample sizes and prevented a finer examination of them. Again, if we would have had a larger sample size, we would have been able to examine smaller effects.

Our study shows that scholarship recipients were a heterogeneous group that fell along a continuum of having divergent perceptions about the effect of scholarship funding on their decisions to enter STEM teaching and to teach in high-needs schools. However, a caveat about the perception of the funding is warranted. It is unclear as to how these clusters differ beyond the perceptions of funding on their decisions and what their perceptions actually mean. For example, will these clusters mirror their commitment to remain teaching in STEM fields and at high-needs schools? Will teachers who are highly committed to STEM teaching and high-needs schools remain longer than those with lower commitment that were more influenced by the funding? Coladarci (1992) and Day,

Elliot, and Kington (2005) have reported that teachers with low commitment to teaching are much more likely to leave the profession. Thus, the scholarship may not influence a teacher's decision to remain in teaching or teach in a high-needs school beyond the commitment necessary for the scholarship. However, as attrition rates have been shown to taper off after three years (Grissmer & Kirby, 1997), it is possible that some of the teachers who were less committed initially would still remain.

The results of this research should benefit STEM teacher preparation programs and researchers interested in the influence of teaching scholarships for recruiting high-quality STEM teachers and STEM majors into teaching at high-needs schools. Significant variables identified here can be used as screening criteria when trying to examine how best to allot scholarships for recruiting STEM majors into teaching. Additionally, our results show that STEM teachers possessed varied views about the influence of funding and our study can serve as a starting point for future work. Future work identifying commonalities and differences of scholarship recipients within and between clusters, especially for the low commitment and highly committed to teaching but not high-needs clusters, would greatly benefit STEM teacher preparation programs so that faculty and scholarship committees can target and recruit these individuals.

Future work is needed to further elucidate differences between these clusters. As these clusters do not seem to differ greatly in demographics, future work should target various factors and constructs that are not readily visible that may be responsible for the development of these three disparate clusters. For example, studies could examine the various reasons for going into teaching (e.g., intrinsic and extrinsic factors). This information would help us to better understand these clusters.

In summary, the importance of this study lies in the development of three clusters from these four variables. These groups differ in their perception about the influence of funding on their teaching decision. This study also teased apart differences in these clusters (both demographics and perceptions) that can be used for recruitment, however, more work remains to be done. Our results are congruent with other studies (e.g., Brookhart & Freeman, 1992; Guarino et al., 2006; Watt & Richardson, 2008) that show that teachers are a multifaceted group that enter teaching for a myriad of reasons. Our study corroborates that STEM teachers should not be treated as a single entity and that they are a diverse group that lies on a continuum of commitment to teaching. Scholarship programs, such as the Noyce scholarship, could use the results presented here in conjunction with future research that further teases apart the clusters, to optimize their distribution of scholarships to those scholars most influenced by them. This optimization of financial incentives is a necessary component of attracting and retaining high-quality STEM majors into teaching. Attracting and retaining high-quality STEM majors into teaching careers is essential for the United States to remain a leader in science, technology, engineering, and mathematics.

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Authors' Notes

This project was funded by National Science Foundation Grant#REC0514884. Christopher David Desjardins' work on this project was supported by the Interdisciplinary Education Sciences Training Program IES Award # R305C050059 University of Minnesota PRF# 473473.

We also wish to thank Allison Kirchhoff and Christina Madsen for their assistance with literature review and data collection.

The Cumulative and Residual Impact of a Systemic Reform Program on Teacher Change and Student Learning of Science

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This longitudinal, five-year study of teachers and students who had participated in a systemic reform program in science explored if (1) teacher change in practice realized during a three-year program is sustained one, two, and three years following the program, (2) student performance on state science assessments two years following studying with teachers at this school still demonstrated significant differences from students who attended the control school, and (3) student performance continued to be enhanced for both White and Minority students. Student achievement was assessed using the Discovery Inquiry Test in Science during sixth through eighth grades and the Ohio Graduation Test was used in 10th grade. The same students completed the test in grades 6–8 and 10th grade. Students from the Program school significantly outperformed students who attended the control school on the 10th grade state assessment in science. Findings in this study revealed the ability for sustained, whole-school, professional development programs to have a cumulative and residual impact on teacher change and student learning of science.

Student learning of science and mathematics has grown increasingly more critical in recent years. Today, success in college, economic growth and development, national security, and competitiveness in the global market all depend on a strong foundation in science and mathematics (Business Roundtable, 2005; Committee on Prospering in the Global Economy of the 21st Century, 2007; U.S. Commission on National Security/21st Century, 2001). However, the achievement gap continues to persist in science between the United States and other countries (Programme for International Students Assessment, 2006) and between white and underrepresented students within the United States (Gonzales, Guzman, Partelow, Pablke, Jocelyn, Kastberg, & Williams, 2004). The achievement gap in science in the United States between African–American and White school children remains quite large. Eighth graders on the National Assessment of Educational Progress experienced a gap of 89 points between African–Americans and Whites and 19 points between African–Americans and Hispanics. About 12% of African–Americans 16 to 24 years old did not graduate high school in 2004 (National Center for Education Statistics, 2006). This compares to just under 7% of White Americans. Students in the United States are now being left behind in science, and the lack of preparation of students may have detrimental impact on the future of our nation (Committee on Prospering in the Global Economy of the 21st Century). There is a need to determine how the teaching of science can be systemically reformed so that all students may be successful (Wojnowski, Bellamy, & Cooke, 2003).

Research on systemic reform efforts is lacking, as there is a dearth in the literature regarding successful programs relating to science performance for diverse learners specifically (Fraser-Abder, Atwater, & Lee, 2006). Often schools engaged in a reform effort experience *turbulence* or external variables such as district level decisions and shifts (Johnson & Marx, 2009) that may influence the degree to which a program is implemented and, in turn sustained, due to internal and external technical, political, and cultural barriers. Teacher beliefs, science content knowledge, administrative support, resources, and accountability demands are just a few sources of turbulence that may influence science reform (Anderson, 2002; Anderson & Helms, 2001; Geier et al., 2008; Johnson, 2007b;

Kahle,Meece, & Scantlebury, 2000). Teacher beliefs, as Gess-Newsome (2003) argued, are integral to reform as "the nature of beliefs held by teachers may ultimately make the difference in the success or failure of the current wave of reform" (p. 11), as Keys and Bryan (2001) found that teacher beliefs, "substantially affect planning, teaching and assessment" (p. 636).

In many schools across the nation, the quality of instruction provided to students varies by teacher due to insufficient science content knowledge and/or teaching strategies that enable student-centered science instruction (Crawford, 2000; Johnson, Kahle, & Fargo, 2007a; Keys & Bryan, 2001; Wright, Horn, & Sanders, 1997; Wright & Wright, 2000). In fact, a synthesis of the NSF supported Local Systemic Change (LSC) program revealed that only 14% of science lessons observed across the nation were of high quality, as defined by "providing students an opportunity to learn important science concepts" (Banilower, Smith, Pasley, & Weiss, 2006, p. 376). Wright and Wright argued that "Teachers and administrators are products of a traditional school experience that has not taught, modeled, or supported the very principles that the standards define" (p. 138). Effective teaching of science, as delineated in the *National Science Education Standards* (NSES; National Research Council [NRC], 1996), includes inquiry as the main strategy for teaching science. This includes allowing students to take control of their own learning and focus on real-life issues that have meaning for them through student-centered experiences. According to the NRC, when students engage in inquiry, they "describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others" (p. 8). Von Secker and Lissitz (1999) explained that inquiry-based instruction is "a student-centered instructional environment that engages students in socially interactive scientific inquiry and one that facilitates lifelong learning" (p. 1110). Given the urgent need promulgated by the lacking number of effective science classrooms across the nation, the increased focus on global competitiveness, and the disparate needs of urban schools and diverse student populations, it is time to further investigate and identify reform programs that can cause a transformational shift in science education resulting in sustained and improved student outcomes and instructional quality.

The NSES detailed effective science teaching strategies and igniting a spark in reforming science teaching (NRC, 1996). However, this was followed by No Child Left Behind (NCLB) legislation (2000), which shifted the focus to reading and mathematics performance as a measure of a school's adequate yearly progress, resulting in funding for science teacher support and science instructional time to be diminished. In 2007, NCLB-mandated state assessment of science began and along with the new accountability came a renewed interest in linking the use of inquiry to student performance on high-stakes assessments (Geier et al., 2008). Moreover, school-level performance on "high-stakes" assessment is the primary measure of educational quality in the United States and there is an increasing need to link science reform programs to these student outcomes to be deemed high quality as well.

Most science reform initiatives in the past have focused on assessing student performance through pre/post assessments across each year of implementation (Lynch, Kuipers, Pyke, & Szesze, 2005; Marx et al., 2004; Rivet & Krajcik, 2004). Though these evaluations are a good measure of specific concepts from individual programs, they provide little indication as to how student performance on state mandated assessments might be influenced. There are also several programs who have utilized state assessment scores at the teacher or school level to determine efficacy of intervention (Czerniak, Beltyukova, Struble, Haney, & Lumpe, 2005; Kahle et al., 2000; Schneider, Krajcik, Marx, & Soloway, 2002; Von Secker & Lissitz, 1999) though this level does not provide student-specific performance data. The most desirable, though very uncommon, evaluation of a systemic reform program is to examine high-stakes assessment data at the student level. As Geier et al. (2008) stated, "The lack of student-level distal standardized test data to demonstrate achievement gains from standards-based inquiry science curricula remains a weakness in the literature" (p. 924).

Conceptual Framework

Systemic reform efforts often are achieved through professional development (PD) program partnerships. PD has frequently been used as a means to increase teacher effectiveness, and millions of dollars have been provided in funding for programs (Banilower, Heck, & Weiss, 2007; Guskey, 2002; Jeanpierre, Oberhauser, & Freeman, 2005; Johnson, 2007a;

Johnson et al., 2007a). Unfortunately, PD programs are often unsustained and do not result in systemic changes in schools and districts, due either to lack of program impact or inability of schools to maintain momentum. Desimone, Porter, Garet, Yoon, and Birman (2002) argued that "collective participation of groups of teachers from the same school, department, or grade level" should be the focus of PD, "as opposed to the participation of individual teachers from many schools" (p. 83). Over the past decade, PD programs have evolved from a focus on individual teacher growth to an emphasis on systemic reform-based efforts.

Though promising results have been documented from programs of the past, the lack of systemic design has not resulted in change outside individual teachers' classrooms. Additionally, research has failed to clearly demonstrate systemic reform opportunities result in sustained changes in teacher practice and increased student science performance that is retained after the program ends (Shymansky, Yore, & Anderson, 2004; Supovitz, Mayer, & Kahle, 2000). This failure may be due to the expense and difficulty of following teachers and students after a program ends or the tendency for effects of PD to diminish along with program support (Banilower et al., 2007).

In order to better understand the complexity of system reform programs, it is important to consider the social, personal, and PD while participating in a program (Bell & Gilbert, 1996). Time is needed to realize desired changes in beliefs and classroom practice (Anderson, 2002; Fullan, 2001; Johnson et al., 2007a) as teachers navigate through the series of events enabling them to experience social, personal, and professional growth and as teachers become empowered and form relationships with each other, which may be the foundation for further improvements in practice (Bell & Gilbert; Johnson, 2007a). A key component of successful PD programs is the creation of professional learning communities. As Grossman, Wineburg, and Woolworth (2001) and Dufour and Eaker (1998) have suggested, there are four stages through which groups much navigate in order to become an effective professional learning community and these are: (1) a nominal stage, or pseudo-community, characterized by both excitement and uncertainty; (2) a chaos stage in which the discomforts, disagreements, or conflicts avoided in the nominal stage come into the open; (3) an emptying stage in which the barriers to authentic communication crumble and the group emerges with a strong collective identity; and (4) a fully functioning stage in which a group's collaborative learning and growth is truly enabled.

Findings from studies of teacher learning and change identify teacher beliefs as a key factor affecting whether or not instructional practices will be changed and how they will be implemented and sustained (Anderson, 2002; Borko & Shavelson, 1990; Fullan, 2001; Krajcik, Blumenfeld, Marx, & Soloway, 1994). These include not only the beliefs regarding instruction, but also relating to how students learn, how change will be perceived by peers and administration, and beliefs in the context of accountability. Therefore, a focus is needed not only on pedagogical content knowledge, but also on sustained experiences that support teacher social, personal, and professional growth resulting in building collaborative structures and challenging existing beliefs, which collectively enable reform efforts to become systemic (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; Putnam & Borko, 1997). Finally, barriers to professional growth, such as lack of resources and supplies, administrative support, and district and state assessment demands, need to be addressed in the context of the experience (Anderson & Helms, 2001; Johnson, 2006, 2007b).

One of the main criticisms of existing PD programs is the inability to attract all potential participants, including the least effective teachers within the school and/or district. Some reform programs have begun to have a school- or district-level focus, involving many or all science teachers from the same school (Johnson, 2007b; Kimble, Yager, & Yager, 2006; Shymansky et al., 2004). These types of programs include the willing and curious, as well as the reluctant. When all teachers are engaged in effective reform programs, the result has been a conscious effort toward improving instructional practice and increased student learning of science (Johnson et al., 2007a; Kahle et al., 2000; Ruby, 2006).

Now that evidence exists, which indicate that PD programs can result in change, the more important questions to answer are: "Does change in practice last?" and "Does teacher change in practice result in sustained student achievement?"

The research base on maintaining change gained through PD programs is limited. Shymansky et al. (2004) indicated that the field of science education continues "stabbing in the dark" in reference to the

dearth in the literature linking reform programs with teacher and student outcomes. Kimble et al. (2006) followed eight former lead teachers (teachers who implemented the PD sessions with participating teachers in the program) who had participated in the Iowa Scope, Sequence, and Coordination three years after funding ended in order to identify their individual continued use of innovative teaching practices as compared to their use during the program. Teachers in this study demonstrated significant gains using those teaching practices ($F = 15.00, p = .00$) three years after the conclusion of the program. Though the Kimble et al. study makes an important contribution to the literature, it does not reveal whether the experience for average teacher participants or, more importantly, reluctant teacher participants, changed their teaching or if the change was sustained over time. Lee, Buxton, Lewis, and Roy (2006) found that students of teachers who participated in the science reform program experienced cumulative gains if they participated within the program over multiple years in grades three to five.

The research presented in this manuscript will address a twofold need exploring the cumulative and residual impact of science reform including: (1) the relationship between participation in a systemic science reform program and student performance on a high-stakes assessment two years later, and (2) the ability of teachers to sustain instructional effectiveness gains during and after a reform program (Desimone et al., 2002; Geier et al., 2008; Johnson, Kahle, & Fargo, 2007b; Shymansky et al., 2004).

This study examines the experiences of all science teachers in one school (Glendale Middle School) across a six-year period three years during the Discovery Model School Initiative (DMSI) reform program and the three years after participation. Additionally, students who were enrolled in the sixth grade during the first year of the DMSI were also followed across to seventh and eighth grades with final follow-up in 10th grade for performance on the state graduation test (SGT) in science. The cumulative and residual effects of a whole-school, PD reform program (DMSI) on teacher practice and student learning for the three years following the program are the focus of this article.

All of the science teachers participated in the program together, and during the six years of this study there was no turnover in science teachers at Glendale. All teachers experienced improvement in their teaching and students of teachers in the program outperformed their counterparts at the control school during the program (Johnson et al., 2007b). The following research questions were explored in this study:

1. Do DMSI reform program teacher participants experience an increase in instructional effectiveness during and following the program?
2. What is the relationship between student participation in a systemic science reform program (DMSI) and performance on a high-stakes science assessment two years later?

Research Context and Participants

Participants

The study was conducted from 2002 to 2007, and pseudonyms are used for school and teacher names. Schools were invited into the DMSI PD program from 2001 to 2004, with the understanding that all science teachers must participate. This study included all six science teachers at Glendale Middle School, located in a Midwestern state. Teacher participants represented a mix of years of experience, variation in academic degrees, and variation in initial buy-in to the program. Demographic data for teacher participants are found in Table 1. Central Middle School was located in the same district as Glendale and teachers at Central did not participate in any science PD program or school-level reform during the period of this study.

In spring 2005 (eighth-grade year for student participants in this study), Glendale Middle School had a diverse, largely urban population of 800 students with a racial/ethnic makeup of 68% White, 16% African–American, 10% Latino, 1% Asian, and 5% other. Central Middle School's population was very similar with 80% White, 9% African–American, 6% Latino, and 5% other students. The percentage of economically disadvantaged students at Glendale was 38% and at Central it was 35% in 2005. Students in this study who attended Glendale and Central Middle Schools (6–8) both attended Fairday High School (9–12).

PD Intervention

The DMSI program was distinctively different from other existing programs at the time of its inception, as it included all teachers in the same school, provided sustained experience across three years, and emphasized social, personal, and PD, not only specific teaching strategies (Johnson, 2006, 2007b; Johnson et al., 2007b). A primary focus of DMSI is the development of a professional learning community within the school to break down barriers associated with teacher isolation. During the DMSI, Glendale science teachers

Table 1
Science Teacher Participant Demographic Data

Teacher	Grade level taught	Area of certification	Years of science teaching experience at baseline	Years of science teaching experience in 2007
Moore	6th	1-8 elementary education	2	7
Fields	6th	1-8 elementary education	17	22
Hamilton	7th	1-8 elementary education, Master's in science	14	19
Green	8th	18 elementary education	14	19
Donaldson	7th	7-12 biology	1	6
Schott	8th	7-12 earth science	2	7

participated in two weeks of PD during summer. The first summer the program focused on Physics by Inquiry, an accelerated course integrating content and pedagogy (other science content areas were covered the other two summers) where teachers developed a unit of instruction along with the content course which they took back and implemented in their classes the following year. Additionally, teachers participated in monthly (10 per year) half-day sessions across the next three school years onsite at the school. During each release day, teachers were provided time, resources, and support from university faculty to develop additional units of study, as well as integrated math and science projects.

The DMSI was facilitated by a team including a university faculty member "coach," whose background was science education. Other members included all of the science and mathematics teachers, and a building administrator. Collectively, the "team" conducted a needs analysis of the group, developed an action plan for working on the areas of need (including student-centered teaching strategies, use of discourse and questioning strategies, content knowledge, grounding science in the real world, cooperative learning, differentiating instruction, curriculum, and team building), which were the focus of sessions across the three-year program. The PD sessions in years 1 and 2 focused on learning about inquiry and ways to use it effectively, familiarizing teachers with the *NSES* (NRC, 1996), developing inquiry investigations that integrate science and mathematics skills, and building trust and establishing collaborative relationship structures. Teachers were presented with revised state content standards in year two and began to modify their curriculum accordingly using materials that were readily available within the district, but also identifying gaps and additional inquiry-based materials/lessons that needed to be developed. Additionally, incorporating cooperative learning was a focus of year two as teachers completed a book study of *Cooperative Learning* by Slavin (1994). Teachers attended the state science professional conference each year. During year 3, teachers constructed alternative assessments (project-based), conducted peer observations to learn and provide feedback to each other, and designed lessons integrating mathematics and literacy with science through interdisciplinary lessons. Some university credit was provided for the PD program contact hours and activities.

Research Procedures

Research Design. A prospective cohort study was conducted. This study is a continuation of the original three-year study (first phase) of the reform program during its operation at the middle school (Johnson et al., 2007a). This article reports the second phase of the study (years 4–6) during which classrooms were observed longitudinally (using the LSC Classroom Observation Protocol described below) through

unannounced, random visits by two raters who collected data on teacher effectiveness. Two raters were trained according to the guidelines established by Horizon Research, Inc. who developed the five-point Likert scale instrument (see Appendix A) and conducted the evaluation of the LSC programs for NSF. Interrater reliability ranged from 0.80 to 0.87 across the years of this study. During the baseline year (2002) and final year of the program (2004), teachers were observed four times (twice in the fall and twice in the spring). Teachers were observed two times (once in the fall and once in the spring) the year following the end of the program (2005). Teachers were observed once in the spring of each of the final two years of the study (2006, 2007).

Student participants in this second phase study included the same students who attended Glendale Middle School (treatment) and Central Middle School (control). During phase one, all students were followed from sixth grade to eighth grade. Students completed the Discovery Inquiry Test (DIT) at baseline (prior to intervention), as well as at the end of sixth, seventh, and eighth grades. The DIT in science assessment was developed in 1994 by members of Ohio's Statewide Systemic Initiative's academic leadership teams, university science faculty, and other Ohio teachers. Items from the National Assessment of Educational Progress 1990 and 1992 public release version focused on measuring student ability to analyze and interpret data, to extrapolate from one situation to another, and to utilize conceptual understanding were included (Kahle et al., 2000). The DIT includes 29 items (11 focusing on life science, eight on physical science, six on earth and space science, and four on the nature of science) and was validated by a national and international expert panel of science educators. The DIT has high internal consistency reliability, Cronbach's alpha coefficient = 0.94. Findings from analyses of those data indicated a significant difference in student science achievement between the two schools in seventh and eighth grades (Johnson et al., 2007b) but not at baseline or at the end of the sixth grade (see Table 2). In middle school, Glendale students outperformed the students at the control

Table 2
Demographic Characteristics and Assessment Scores for Glendale (Treatment) and Central Middle (Control) School Students

	Baseline: 6th grade August		Year 1: 6th grade March		Year 2: 7th grade		Year 3: 8th grade		Ohio graduation test: 10th grade, Fairday High School	
	G	C	G	C	G	C	G	C	G	C
Students (*n*)	291	209	282	217	212	210	210	215	176	174
Gender (% males)	54	52	53	51	53	47	54	50	53	51
Race (%)										
White	74	78	73	78	69	75	68	80	72	78
African American	11	10	11	10	13	10	16	9	18	12
Other	16	13	16	12	18	15	16	11	10	10
Student assessment scores										
Mean	8.92	8.29	8.93	8.28	12.28	8.17	13.28	8.16	429.35	389.76
SD	3.12	3.99	3.13	3.96	3.16	3.02	3.36	3.19	24.71	24.37
Number of students who received a passing score									156	60

school (Central). The second phase study that is being reported here includes following students as they left their prospective middle schools (and the reform program) and moved on to high school to complete the 10th grade science graduation test. Students take the SGT in 10th grade and then repeatedly in 11th grade and on until they receive a passing score.

Instruments. The LSC Classroom Observation Protocol (Horizon Research, Inc., 2002) was used as the primary teacher effectiveness assessment instrument to determine increase in science teacher effectiveness in four areas: (a) design of lesson, (b) implementation of lesson, (c) science content of lesson, (d) classroom culture. For each observation, a teacher received a score of from 1 (*worst*) to 5 (*best*) on each of the four subscales of the protocol (design, implementation, science content, and classroom culture). The LSC Classroom Observation Protocol rubric can be found in Appendix A.

The SGT is a state-mandated assessment which aligns with state academic content standards in science, mathematics, reading, writing, and social studies which students must demonstrate proficiency on to graduate high school. There are approximately 35 multiple-choice and eight open-response questions on each section (content area) of the assessment. There are four categories which students are placed in, depending on their performance. The categories and score ranges are: advanced (432–508), accelerated (415–431), proficient (400–414), basic (385–399), and limited (251–384). The students who score advanced, accelerated, and proficient "pass" the assessment. Basic and limited scores are considered unsuccessful. SGT scores by student identification number were provided by the participating school districts in this study. Sample DIT and SGT items are found in Appendix B.

Data Analysis

For research question 1, teacher data were analyzed using a series of one-way repeated-measures ANOVAs where Time served as the within-subjects factor or independent variable (levels were baseline, end of program [three years from baseline], and one, two, and three years after end of program [years four, five, and six from baseline]). Each teacher observation subscale (including total scores) served as the dependent variable in a separate analysis. The assumption of sphericity was met for all analyses (Mauchly W, $p > 0.05$). In order to maintain an alpha of 0.05 (Type I error) and to follow the study aims, significant omnibus results were followed by two planned comparisons: (a) scores at baseline versus year 3 (beginning to end of program) to evaluate the effect of the program and (b) scores at year 3 versus year 6 (end of program to three years after program) to assess the sustained or continued growth effect of the program over time. Although only six teachers were included in the analyses, post hoc power was >0.99 for each, indicating sufficient power for these within-subject analyses.

Student 10th-grade scores were compared between those students who had teachers in the intervention versus those that did not using independent-samples t-tests for research question two. Within the intervention group scores from students' scores were compared between White and minority race/ethnic groups using an independent-samples t-test to evaluate whether there were any differences. All analyses were performed using the *R* statistical software (R Development Core Team, 2007).

Results

Growth in Science Teaching Effectiveness

Teachers began the DMSI program at varying levels of effectiveness, ranging from ineffective (1) to beginning effective (3), and continually improved across the program so that at the end no teacher received a score lower than beginning effective (3) on any area of the LSC protocol (Horizon Research, Inc., 2002).

All six years of data from all six participating science teachers were entered into the analyses. There was a significant omnibus effect of Time for all teacher observation domains, and the overall measure of magnitude of effect (η^2) for each omnibus analysis indicated a large effect (>0.20). Table 3 presents results of all statistical analyses. Figure 1 presents mean scores over time for each domain for all teachers. Planned comparisons indicated significant positive change between (a) baseline and year 3 scores for Design and Implementation (as well as Total scores) and (b) year 3 and year 6 scores (continued growth after the program ended) for Content and Culture (as well as Total scores). Although all indices (indicators) of effect size would be considered large, several follow-up comparisons approached but failed to reach statistical significance. However, such differences should be considered educationally significant in terms of absolute change on a five-point Likert scale.

In addition to the overall statistical analyses for the six teachers in this study, it was important to examine

Table 3
Teacher Quality — Results of Omnibus Repeated — Measures ANOVAs and Planned Comparisons

Domain	Omnibus ANOVAs					Baseline vs. year 3				Year 3 vs. year 6			
	F	*df*	*p*	η^2	Power	*F*	*df*	*p*	η^2	*F*	*df*	*p*	η^2
Design	19.98	4,16	0.001	0.83	0.99	18.26	1,4	0.013	0.82	4.38	1,4	0.105	0.52
Implementation	13.83	4,16	0.001	0.78	0.99	17.78	1,4	0.014	0.82	3.08	1,4	0.154	0.44
Content	33.63	4,16	0.001	0.89	0.99	3.33	1,4	0.142	0.46	23.36	1,4	0.008	0.85
Culture	34.43	4,16	0.001	0.90	0.99	3.36	1,4	0.141	0.46	32.03	1,4	0.005	0.89
Total score	29.44	4,16	0.001	0.88	0.99	23.74	1,4	0.008	0.86	11.61	1,4	0.027	0.74

Note. η^2 = eta-squared.

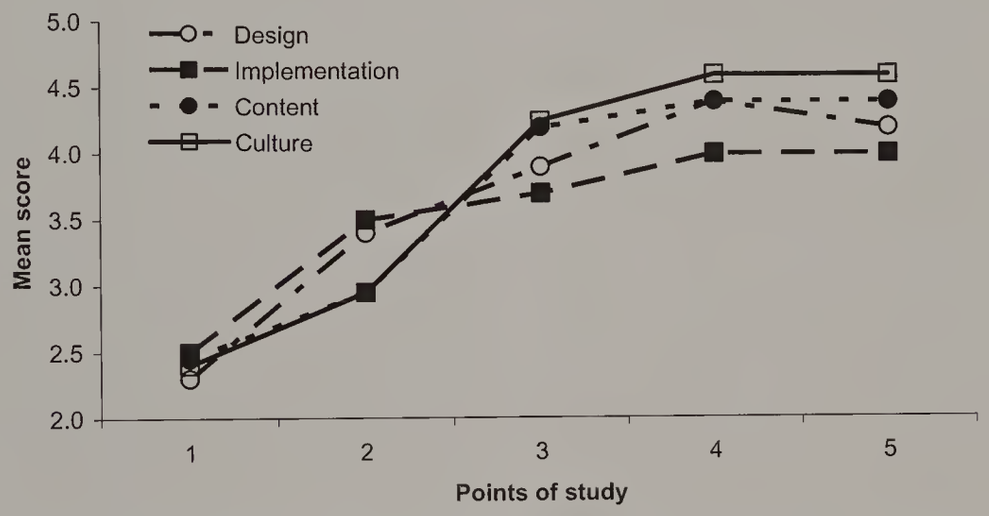

Figure 1. Mean teacher observation domain scores over time. Point 1 = baseline, point 2 = end of program (year 3), point 3 = one year after end (year 4), point 4 = two years after (year 5), point 5 = three years after (year 6).

individual teacher ability to sustain and continue to improve practice after the end of the DMSI program. Each teacher not only improved during the program (some more than others), but also each continued to improve after the program ended (Table 4).

Student 10th Grade SGT Science Assessment Performance

Students who attended Glendale Middle School significantly outperformed students from the control middle school on the 10th grade SGT in science. Student scores from the 10th-grade test were compared between students who had teachers in the intervention and those who did not have teachers in the intervention during middle school. Overall, 156 former Glendale students (treatment) passed the SGT in science, compared to only 60 former Central Middle School students. For those who did not pass the assessment, only 20 were former Glendale students and 114 were former Central students.

For statistical analyses, three comparisons were made: (a) all scores, regardless of where the scores were in relation to the pass/fail cutoff, (b) only passing scores, and (c) only failing scores. Results indicated that in each case scores from students who had teachers in the intervention were significantly higher than those who did not. For instance, the intervention group (M = 429.35, SD = 24.71, n = 176) scored 30 points higher than those in the control group (M = 389.76, SD = 24.37, n = 174), t (348) = 15.09, $p < 0.001$, Cohen's d = 1.63. Additionally, among those students who received a passing SGT score, those in the intervention group (M = 435.37, SD = 18.79, n = 156) scored 20 points higher than those in the control group (M = 145.25, SD = 13.80, n = 60), t (216) = 8.63,

Table 4
Individual Teacher Change over Time on the LSC Protocol (Baseline, End of Progam, Follow-Up [Three Years Later])

Teacher	Design			Implementation			Content knowledge			Classroom Culture		
	Base	End	*F*	Base	End	*F*	Base	End	*F*	Base	End	*F*
Hamilton	3.3	5.0	5.0	3.3	5.0	5.0	3.3	4.3	5.0	3.0	4.0	5.0
Green	3.0	4.0	4.0	3.0	4.3	4.0	3.0	3.5	5.0	3.0	4.0	5.0
Moore	1.0	1.5	3.0	1.0	2.0	3.0	1.0	2.0	3.0	1.0	2.0	4.0
Fields	2.0	3.0	4.25	2.5	3.5	3.75	2.5	2.75	3.75	2.5	3.0	4.0
Donaldson	1.0	2.5	4.0	2.0	2.5	3.0	2.0	2.5	4.0	2.0	1.5	4.0
Schott	3.3	3.8	5.0	3.3	3.8	5.0	3.0	3.5	4.0	3.0	3.3	5.0

$p < 0.001$, Cohen's $d = 1.45$. Finally, among those students who received a failing SGT score, those in the intervention group ($M = 382.40$, $SD = 11.16$, $n = 20$) scored six points higher than those in the control group ($M = 376.34$, $SD = 16.83$, $n = 114$), $t\ (132) = 2.05$, $p < 0.05$, Cohen's $d = 0.36$. The Cohen's d effect size estimate represents a standardized mean difference between the two groups being compared. Thus, the intervention and control groups differed from each other with respect to SGT scores from between 0.36 and 1.63 standard deviations, representing small to large effects, respectively. No difference was found in SGT performance in science between White and minority students who attended Glendale Middle School. When comparing White ($M = 430.07$, $SD = 24.73$, $n = 128$) to minority ($M = 427.42$, $SD = 24.80$, $n = 48$) Glendale students on their 10th-grade SGT scores, there was no statistically or educationally significant difference, $t(174) = 0.63$, $p = 0.5273$, Cohen's $d = 0.11$. Therefore, all students who attended Glendale, irrespective of ethnicity/race, performed similarly on the SGT assessment in science.

In summary, we found that not only did teachers retain their growth in teaching effectivencss measured by the LSC Classroom Observation Protocol after the program ended, but they continued to improve during the three years following the conclusion of the program. Their growth across the program was statistically significant, as well as their growth from the end of the program to the end of this study (three years afterward). Furthermore, this study revealed that students from Glendale whose teachers had participated in the intervention significantly outperformed Central's students on the SGT in science—two years following the end of the program. Additionally, 89% of students from Glendale passed the assessment compared to only 34% of students who had attended Central Middle School. Finally, and possibly most importantly, we were able to build upon previous findings in the larger study (Johnson et al., 2007b), which demonstrated both White and minority students experienced increased science learning in middle school, with findings in this study revealing that all students who attended Glendale performed similarly on the SGT science assessment.

Discussion and Implications

Discussion

This longitudinal study sought to investigate whether a cumulative and residual impact existed following a systemic reform PD program for science teachers and students who attended the school implementing the reform. Accountability is the driving factor behind innovations in the educational system. In the science education realm, inquiry-based instruction is the "central strategy" for guiding learning experiencss (NRC, 1996). However, to this point, there has been a dearth in the literature linking effective science instructional practices, including inquiry, to high-stakes, state-mandated assessments (Geier et al., 2008). In addition, there are even fewer studies that tie PD-based reform programs to state-level student measures (Shymansky et al., 2004). Findings in this study demonstrate the ability of science reform initiatives to have an impact beyond the life of the program with sustained change and gains for both students and teachers. The foundation of the DMSI included a

focus on science teachers' social, personal, and PD, which was facilitated through discourse in the established professional learning community which grew across the program (Bell & Gilbert, 1996; Grossman, Wineburg, & Woolworth, 2001). At the onset of the program, three teachers (Hamilton, Green, and Schott) were using more effective practices than the other teachers (Moore and Donaldson). All teachers continued to improve following the end of the program and all but one became "effective" teachers — scoring a four or five on the LSC protocol. The other teacher improved from an "ineffective" teacher scoring a one to a "neutral" teacher scoring a three.

When the DMSI program ended and monthly time to collaborate had vanished, teachers continued their process of growth and found alternative times to meet (shared through conversations with teachers during observation visits), as they moved into the final stage of social and personal development, "initiating collaborative ways of working" and "feeling empowered" (Johnson, in press). Additionally, by the end of the program, the professional learning community had been established and was fully functioning enabling collaborative learning and growth (Grossman et al., 2001) as was revealed through teacher interviews that were part of the larger study. As a result of these areas of success, individual and collaborative PD continued following the program in informal settings. Teachers continued to refine their practice and realize gains in teaching effectiveness through initiating other development activities such as study groups and attending state and national science association meetings (Johnson, 2009).

The DMSI was conducted across a three-year span of over 80 contact hours per year. All science teachers from Glendale Middle School participated in the program learning about inquiry and other effective strategies for science teaching. Teachers aligned their instruction to meet the revised state science content standards and to complement the curriculum in each grade. When program funding ended in 2004, the collaborative relationships established through the reform program at the school were maintained, as well as the infrastructure for success (Johnson, 2009).

Increased student science learning was shared as a positive reinforcement for teachers in the study to continue to implement new strategies and to continue to improve their teaching (Johnson, in press). Glendale students realized statistically significant gains on the DIT in Science in seventh and eighth grades; whereas students at the control school showed little to no growth across the three years (Johnson et al., 2007b). Glendale students were exposed to a mix of three (sixth, seventh, and eighth grade) participating teachers in the program. As a result, students from Glendale significantly outperformed students who attended Central Middle School on the SGT in science in 2007.

According to the NRC (1996), students who participate in an effective science program ask questions, plan, and conduct their own investigations, use appropriate tools and techniques to gather data, think critically and logically about the relationships between evidence and explanations, construct and analyze alternative explanations, and communicate findings in the form of scientific arguments. Former Glendale students may have had their capability and context beliefs transformed — as a result of their classroom experiences — which translated into successful learning. Von Secker and Lissitz (1999) have argued that "a student-centered instructional environment that engages students in socially interactive scientific inquiry and one that facilitates lifelong learning" (p. 1110). This may be the reason 89% of former Glendale students passed the SGT science assessment — compared with only 34% of Central's former students. In the context of state performance, over 37,000 students did not pass the SGT in science. An average of 72% of the students who took the test passed the science section the year of this study. It is important to note that the SGT is given at the 10th-grade level then subsequently in 11th and 12th grades until students pass all parts. These figures for the state include the students repeating the test.

This study yielded promising indications of the sustainability of gains from a reform program, the ability to produce further gains after the program ends, and the performance of students in years following on state science assessments. A limitation of this study, however, is that it consisted of science teachers from only one school. Therefore, without a comparison group of teachers who did not experience the PD program, some may argue that the alternative hypothesis that teachers improved naturally through maturation and experience. However, in our other research with a similar implementation of this model, teachers who did not participate in the program experienced a decline along with their students' performance (Johnson & Fargo, in press). The students in this study came from Glendale and Central Middle Schools so

there was a treatment and comparison group. Limitations exist, though the data from this study are promising, the generalizability is limited.

Implications

As we have argued in this article, it is essential that science education reform efforts be designed in a sustainable model that will translate into direct impact on student learning outcomes — specifically on high-stakes assessments. Change in practice takes time to be realized and must occur and be effectively implemented in order for students to begin their change process — taking on a more student-centered role in the science classroom (Fullan, 2001; Johnson et al., 2007b). Change for students also takes time — as in many cases, students have become accustomed to the isolated role they play in the learning process (Anderson & Helms, 2001). Participation in inquiry and standards-based science classrooms requires many fundamental changes in student routines, and thinking. Once teachers and students become acclimated into the new instructional paradigm, then student outcomes will begin to demonstrate the positive impact. Again, systemic reform takes time. Unfortunately, struggling schools, as well as the NCLB legislation as written itself, work against a systemic model of reform — as time is short when it comes to making improvements in the system.

This study provided insight into the complex nature of systemic reform efforts — specifically, sustained PD programs focused at the school level. Though many variables are hard for PD providers to control for, many may not be a direct influence on the outcomes of the program if sufficient time is provided for social and personal development to take place, through the context of the development of a functioning professional learning community (Bell & Gilbert, 1996; Cohen & Hill, 2000; Grossman et al., 2001). In this study, teacher participants in the school were provided support enabling the formation of a professional learning community that continued to drive their personal and collective growth following the end of the program (Johnson, 2009). Berns and Swanson (2000) argued, "Principal support, coupled with school culture that both values science as a core subject and provides an overall culture to support reform, is all too rare" (p. 11). This foundation is essential for changes in practice to be transformed into routine instructional practices for teachers.

Systemic PD reforms are an investment in the future that often does not reap the rewards we would prefer, mainly, lasting change beyond the life of the program. Findings from this longitudinal study suggest that not only can statistically significant gains occur during a program for both teachers and students, but they can be sustained for years after the program ends.

The larger contributions to the knowledge base that can be gleaned from the findings in this study are that school-based systemic PD reform programs in middle-school science can: (1) transform the teacher quality and enhance student learning of science during the program, (2) result in a cumulative and residual impact on teacher quality that results in continued growth following the program, and (3) better prepare students with a foundation in science that enables them to experience continued success in science at the high school level and on high-stakes graduation assessments.

Further research is needed to follow similar school-based systemic reform programs and other delivery modes of science PD programs to assess if changes realized during PD are retained after the program ends. There is a need to learn which types of PD result in change that is sustained beyond funding. Moreover, the ultimate goal of improving science teacher effectiveness is improved student learning. Further work is needed to determine the lasting impact of these environments on student preparation to succeed in science, mathematics, technology, and engineering fields of study.

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Appendix A

Local Systemic Change Classroom Observation Protocol — Capsule Description of the Quality of the Lesson

Level 1: Ineffective Instruction

There is little or no evidence of student thinking or engagement with important ideas of science. Instruction is *highly unlikely* to enhance students' understanding of the discipline or to develop the capacity to successfully do science. Lesson was characterized by either

a. **Passive learning**
   Instruction is pedantic and uninspiring. Students are passive recipients of information from the teacher or textbook; materials is presented in a way that is inaccessible to many of the students
b. **Activity for activity's sake**
   Students are involved in hands-on activities or other individual or group work, but it appears to be activity for activity's sake. Instruction lacks a clear sense of purpose and/or a clear link to conceptual development.

Level 2: Elements of Effective Instruction

Instruction contains some elements of effective practice, but there are *serious problems* in the design, implementation, content and/or appropriateness for many students in the class. For example, the content may lack importance and/or appropriateness; instruction may not successfully address the difficulties that many students are experiencing. Overall, the instruction is *very limited* in its likelihood to enhance students' understanding of the discipline or to develop their capacity to successfully do science.

Level 3: Beginning Stages of Effective Instruction

Instruction is purposeful and characterized by quite a few elements of effective practice. Students are, at times, engaged in meaningful work, but there are *weaknesses*, ranging from substantial to fairly minor, in the design, implementation or content of instruction. For example, the teacher may short-circuit a planned exploration by telling students what they "should have found"; instruction may not adequately address the needs of a number of students; or the classroom culture may limit the accessibility or effectiveness of the instruction. Overall the instruction is *somewhat limited* in its likelihood to enhance students' understanding of the discipline or to develop their capacity to successfully do science.

Level 4: Accomplished, Effective Instruction

Instruction is purposeful and engaging for most students. Students actively participate in meaningful work (e.g. investigations, teacher presentations, discussions with each other or the teacher, reading).The instruction is well-designed and the teacher implements it well, but adaptation of content or pedagogy in response to student needs and interests is limited. Instruction is *quite likely* to enhance most students' understanding of the discipline and to develop their capacity to successfully do science.

Level 5: Exemplary Instruction

Instruction is purposeful and all students are highly engaged most or all of the time in meaningful work (e.g. investigations, teacher presentations, discussions with each other or the teacher, reading). The lesson is well designed and artfully implemented, with flexibility and responsiveness to students' needs and interests. Instruction is *highly likely* to enhance most students' understanding of the discipline and to develop their capacity to successfully do science.

Appendix B

Sample DIT and OGT Assessment Items

DIT Item #4

Which of the following objects has the most inertia?

a. a 50-kilogram rock
b. a 100-kilogram football player
c. an automobile
d. an oil tanker

DIT Item #5

You want to find out which would empty from a can the fastest — water, alcohol, cooking oil, syrup, or soda pop. To answer this question you will need equal amounts of the liquids as well as which of the following?

a. a can with a hole in the bottom and a stopwatch
b. a stopwatch only
c. cans with different size holes
d. cans of different sizes, one for each liquid

OGT — Science, 2007 Items #8 & 9

On a humid summer day, Franklin put six ice cubes into each of two cups and then poured the same amount of lemonade into each cup. Cup A was made of plastic, and Cup B was made of glass. He left the cups for about 20 minutes and then came back. He found a small puddle of water around Cup A and a larger puddle around Cup B. Franklin determined that the cups were not leaking.

8. Which is the best explanation for the small puddle around Cup A and the larger puddle around Cup B?
   a. Cup A contained more ice than Cup B.
   b. Cup A was a better insulator than Cup B.
   c. Cup A had a greater volume of lemonade than Cup B.
   d. The contents of Cup A were initially colder than the contents of Cup B.
9. Suppose Franklin had a third cup, made of Styrofoam®, to which he added the same number of ice cubes and the same amount of lemonade. What would Franklin expect to observe after 20 minutes?
   A. The Styrofoam cup would have a smaller puddle than either the glass or plastic cup.
   B. The Styrofoam cup would have a larger puddle than either the glass or plastic cup.
   C. The Styrofoam cup would have a puddle exactly the same size as the plastic cup.
   D. The Styrofoam cup would have a larger puddle than the plastic cup but a smaller puddle than the glass cup.

Student Initiatives in Urban Elementary Science Classrooms

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Student initiatives play an important role in inquiry-based science with all students, including English language learning (ELL) students. This study examined initiatives that elementary students made as they participated in an intervention to promote science learning and English language development over a three-year period. In addition, the study examined whether student initiatives were related to other domains of classroom practices. The study involved 70 third-, fourth-, and fifth-grade classrooms with ELL students in six urban elementary schools. Results indicated that students generally made few, low-quality initiatives. Student initiatives were generally not related to the other domains of classroom practices for grades 3 and 4, whereas initiatives were significantly related to almost all the other domains for grade 5. These results contribute to the knowledge base for fostering ELL students' initiatives in science classrooms.

An important focus in recent science education reform documents has been on the use of inquiry approaches in the classroom (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996, 2000). In accordance with such approaches, students would be expected to spontaneously raise questions, offer insights and comments, and interject arguments into classroom discussions. These reform efforts require students to go beyond simply following a list of directions or repeating back information from a teacher or text and instead, to initiate participation that both advances engagement with the lesson and demonstrates involvement in the process of inquiry. In inquiry-based science instruction, student initiatives serve as the basis for the development of science investigations. They not only help deepen student understanding of particular scientific concepts, but also indicate that students are developing a sense of the way science works. For example, one type of initiative — student questions — is seen as the heart of the scientific process and a vital part of problem solving (Rop, 2002; Shodell, 1995). Thus, when students are engaged in making such initiatives in science, they are achieving important learning goals.

The call in reform documents for greater inclusion of inquiry practices in science classrooms has resulted in additional pressures on teachers. Many elementary teachers lack sufficient knowledge of science content and reform-oriented teaching practices. As a result, their ability to support inquiry practices with their students is limited (Garet, Porter, Desimone, Birman, & Yoon, 2001; Kennedy, 1998). Making this task even more complicated is the ever increasing diversity of the classroom and the additional tools teachers need to effectively teach science to all students. With science now included as part of high-stakes testing and accountability in the United States, science teachers are in great need of fostering inquiry practices with a diverse student population.

In spite of this emerging need to promote science inquiry with English language learning (ELL) students, the research is limited. While ELL students must learn science and English language and literacy simultaneously, research traditions and teacher education programs have kept these two areas largely separate (Lee, 2005). However, it is important to consider their interaction. For example, teachers' efforts to introduce elements of inquiry-based science may contradict their students' cultural norms, resulting in the undesired

consequence of limiting student involvement. ELL students should have opportunities to participate in science inquiry that is supported by a high-quality science curriculum guided by science education reform (NRC, 2000). Science curriculum designed for ELL students to engage in science inquiry and make initiatives during the inquiry process is especially needed to ensure equitable learning opportunities for these students (Lee & Buxton, 2008).

In order to better understand how ELL students become engaged in science inquiry, we examined the numbers and types of initiatives they made during their science lessons. This study took place as part of a five-year research and development project focused on implementing curriculum units and teacher professional development workshops. The intervention is aimed at promoting science and literacy achievement of ELL students in urban elementary schools at a time when science is becoming a part of accountability policies in the United States. The project involves teachers and students in grades 3 through 5 at 14 elementary schools in a large urban school district. All of these schools enroll high proportions of ELL students and students from low socioeconomic status (SES) backgrounds, and have traditionally performed poorly according to the state's accountability plan.

Research Questions

Our intervention highlighted inquiry-based science by providing scientific and linguistic scaffolding for ELL students and students from low SES backgrounds as they learned to engage in practices of science in urban elementary schools. This study examined initiatives that third-, fourth-, and fifth-grade students made as they learned a new series of science curriculum units over a three-year period (2004 through 2007). We developed a classroom observation scale to numerically rate the frequency and quality of student initiatives in terms of procedural, factual, or conceptual initiatives. In addition, the study examined whether student initiatives were related to other domains of classroom practices, including teacher knowledge of science content, teaching science for understanding, teaching science for inquiry, and teacher support for English language development. Specifically, the study examined the following research questions:

1. What were the frequency and quality of student initiatives during observed lessons in terms of (a) procedural, (b) factual, and (c) conceptual initiatives?
2. How were student initiatives related to four domains of classroom practices, including (a) teachers' knowledge of science content, (b) teaching practices to support scientific understanding, (c) teaching practices to support scientific inquiry, and (d) teaching practices in science to support English language development?

Literature Review

In this section, we discuss the literature on elementary student initiatives, especially ELL students, in science classrooms. Then, we discuss initiatives in relation to the larger context of classroom practices that promote understanding, inquiry, and English language development of ELL students in science classrooms.

Initiatives by ELL Students in Science Classrooms

Student initiatives in science classrooms are an important goal of reform documents (AAAS, 1993; NRC, 1996). In an idealized classroom we might expect students to raise substantive questions that would then be explored in scientific investigations. For example, *Inquiry and the National Science Education Standards* (NRC, 2000) begins with a question raised by students about the mysterious decline of the health of a group of schoolyard trees. In this scenario, the teacher developed a long-term investigation built on student initiatives. This example is put forth as a model about ways that teachers who are sensitive to the importance of questions in the scientific process can use student initiatives to guide science inquiry.

Science curricular and instructional interventions recognize the importance of student initiatives in the scientific process. In a study of elementary science classrooms to examine questioning, Watts and Alsop (1995) found that teachers solicited several types of questions. Teachers asked students to generate questions when they were creating their study topic, when they were confronted by a puzzling situation, and after they had answered another question. In a study of scientific question-posing capabilities among 10th-grade students who were cooperatively studying air quality, they were asked to generate as many questions as possible about a scenario (Dori & Herscovitz, 1999). The results indicated an increase in both frequency and complexity of student questions as well as an increase in science achievement. In another study examining students' abilities to generate scientific questions, ninth-grade biology students working in groups to learn about food and nutrition were asked to record questions they generated in individual logs

(Chinn & Chia, 2004). The results indicated that initial questions that they asked were generally broad, unfocused, and related to disparate topics but that the later questions in collaborative groups were more topic-specific and focused.

Despite the apparent importance of student initiatives in the science education reform literature and in the curriculum itself, two distinct literatures suggest that ELL students in particular may be reluctant to proffer such initiatives in the science classroom. One area of literature on classroom science discourse has examined common understandings that students develop about what and how things can be said in classrooms (Edwards & Mercer, 1987; Lemke, 1990). Lemke found that science classrooms frequently follow a speech pattern where the teacher raises a question, the student answers, and the teacher follows with an evaluative remark. If students interrupt this pattern with a question or comment, teachers try to guide them back to resume this sequence. Along these lines, Rop (2002) found that although high school science teachers valued student questions as indicative of student understanding, they felt pressure to cover the curriculum and thus saw student questions as interruptions to the flow of the lesson. Given these constraints, it would seem that most classrooms would offer little support for student initiatives. In the classrooms following the usual teacher–student speech pattern, ELL students are even less likely to make initiatives as they struggle to learn the academic content of science in a language they are in the process of acquiring.

The second area that speaks to initiatives by ELL students is the study of cultural experiences that students bring to the science classroom. In some cultures, children are somewhat restricted in conversational activities since questions posed to an adult may be viewed as an attempt to undermine adult authority (McKinley, 2007; Rogoff, 1990). To the degree that teachers are respected as authority and sources of knowledge, students may be reluctant to raise questions if their culture considers this to be a sign of disrespect. In other cultures, students may not want to volunteer answers in order to avoid calling attention to themselves (Nelson-Barber & Estrin, 1995; Solano-Flores & Nelson-Barber, 2001).

Initiatives by ELL Students Related to Other Domains of Science Classroom Practices

Student initiatives may be encouraged or hindered in different classroom environments. Classrooms where teachers exhibit more science knowledge and more effectively facilitate student understanding, inquiry, or language development might also be contexts where students make more initiatives. This is particularly relevant to ELL students depending on whether teachers assume that ELL students must acquire English before learning science or whether teachers integrate science with English language and literacy (Fathman & Crowther, 2006; Lee, 2005).

It seems self-evident that teachers need to know the subject matter that they are required to teach (Kennedy, 1998). They should have deep and complex understandings of science concepts, be able to make connections among science concepts or topics, and be able to apply science concepts to explain natural phenomena or real-world situations. Only with sufficient science content knowledge, can teachers employ reform-oriented practices that ultimately lead to student understanding and inquiry.

Science education reform stresses students' understanding of science (AAAS, 1993; NRC, 1996, 2007). Teachers should recognize the role of prior knowledge, particularly science misconceptions, in shaping students' understanding of natural phenomena. Additionally, they should enable students to recognize problematic and incomplete information, make reasoned and well-supported arguments, and justify solutions based on evidence.

Scientific inquiry is a powerful way of understanding science content (NRC, 2000). Students learn how to ask questions and use evidence to answer them. In the process of conducting scientific inquiry, students learn to design an experiment, collect evidence from a variety of sources, develop an explanation from the data, and communicate and defend their conclusions.

ELL students benefit greatly from hands-on and inquiry-based science instruction (Lee, 2002; Rosebery, Warren, & Conant, 1992). Hands-on activities are less dependent on formal mastery of the language of instruction and, thus, reduce the linguistic burden on ELL students. Hands-on activities through collaborative inquiry foster language acquisition in the context of authentic communication about science knowledge and practice. Hands-on activities based on natural phenomena are more accessible to students with limited science experience than is decontextualized textbook knowledge. Finally, hands-on inquiry can serve as a catalyst to promote students' communication of their scientific understanding in a variety of formats, including gestural, oral, pictorial, graphic, and textual.

Once teachers are made aware of the additional challenges in teaching science to ELL students, they need to learn strategies to meet these students' learning needs (Wong-Fillmore & Snow, 2002). First, teachers of ELL students need to create classroom environments that promote the development of general and content-specific academic language. Second, teachers should view language from a human development perspective and formulate developmentally appropriate expectations about language comprehension. Third, teachers should apply this knowledge to the teaching of academic content areas. As a result, teaching practices will emerge that engage students of all levels of English proficiency in academic language learning, offer multiple points of entry for students at different levels of English proficiency, and provide multiple modes for students to display their science learning.

Method

Research Setting and Participants

This study was conducted in a large school district located in the Southeastern United States. The district is composed of a linguistically and culturally diverse student population. During the 2004–2005 school year (the first year of the study), the student population in the school district was 60% Hispanic, 28% Black (including Haitian and Caribbean Islanders), 10% White non-Hispanic, and 2% Asian or Native American. Across the district, 72% of elementary students participated in free or reduced price lunch programs, and 24% were categorized as limited English proficient (LEP) according to the state definition.

In May 2004, schools were invited to participate in a five-year research and development project based on three criteria: (a) percentage of ELL students (predominantly Spanish or Haitian Creole-speaking students) above the district mean at the elementary school level (24%), (b) percentage of students on free or reduced price lunch programs above the district mean at the elementary school level (72%), and (c) poor school performance (i.e., school grades of primarily C or D according to the state's accountability plan). Of the 206 elementary schools in the district, 33 met these criteria and 14 agreed to participate. During the three years of the project (2004–2007), six schools participated in the treatment group and eight schools served as the comparison group. This study involved only the six treatment schools that continued their participation during the three years.

Over the first three years (2004–2007) of the five-year intervention, third-grade teachers started their participation during the first year (2004), fourth-grade teachers during the second year (2005), and fifth-grade teachers during the third year (2006). All third-, fourth-, and fifth-grade teachers in each of the six treatment schools participated in the professional development intervention described below. Only those teachers who were observed twice in their respective first year of the intervention were included in this study. Based on these criteria, the study involved 33 out of 39 third-grade, 21 out of 24 fourth-grade, and 16 out of 20 fifth-grade teachers, for a total of 70 elementary teachers. It is noted that the reduced sample size in the study reflects teacher mobility within the school year, which is a common problem in urban schools (Loeb, Darling-Hammond, & Luczak, 2005), rather than incomplete data collection. It is also noted that the number of third-grade teachers is larger than the number of fourth- or fifth-grade teachers. Third-grade teachers tended to teach all subject areas including science in smaller class sizes, compared with fourth- and fifth-grade teachers who tended to be departmentalized in specific subject areas and teach larger class sizes.

Professional Development Intervention

The intervention was comprised of (a) curriculum units, including student books, teachers' guides, and science supplies and (b) teacher workshops throughout the school year. The curriculum units and workshops were designed to complement and reinforce each other for the improvement of teachers' knowledge and practices in science instruction along with English language development of ELL students.

Curriculum Units. A series of curriculum units was developed to constitute the entire science curriculum for grades 3 through 5 as mandated by the state science content standards and recommended by the *National Science Education Standards* (NRC, 1996). The content of the units for each grade is presented in Table 1. For each unit, classrooms are supplied with teachers' guides, student books, and science supplies.

The teachers' guide for each unit provides an overview of how to teach that particular unit with ELL students. It begins with an explanation of (a) how to promote students' science inquiry and understanding of key science concepts and "big ideas" (patterns of change, systems, models, and relationships) to explain natural phenomena and (b) how to incorporate English

Table 1
Curriculum Units for Each Grade Level

Grade 3	Grade 4	Grade 5
Measurement	Energy	Nature of Matter
States of Matter	Force and Motion	Earth Systems
Water and Weather Cycle	Processes of Life	Synthesis

language and literacy development as part of science instruction. Then, for each lesson, specific strategies are offered to promote science learning and English language development in student books and teachers' guides, described next.

Student books are designed to promote standards-based, inquiry-driven science learning. The units are designed to move progressively along the continuum of teacher-explicit to student-initiated inquiry and to increase the complexity of science concepts as students move through the units. In addition, the books emphasize key science concepts and big ideas. Teachers' guides provide content-specific teaching strategies for each lesson, including suggestions on how teachers may provide different levels of guidance and scaffolding. They also offer suggestions about how to set up and implement hands-on activities, along with cautions about what may go wrong and how to respond to such situations. Additionally, they provide science background information and explanations for the questions posed in the student books, with a particular emphasis on students' common misconceptions and learning difficulties.

Both student books and teachers' guides highlight activities and strategies to foster reading and writing during science instruction. For example, they incorporate comprehension questions about inquiry activities; various language functions (e.g., describing, explaining, reporting, drawing conclusions) to promote science inquiry; and use of hands-on tasks, narrative vignettes, and expository texts related to everyday experiences. They also address the needs of ELL students by providing explicit guidance to promote their English proficiency. For example, the language load for students at varying levels of English proficiency becomes increasingly more demanding as they progress from grade 3 through 5. Key science terms are provided in English, Spanish, and Haitian Creole to support communication and comprehension. Additionally, the units use multiple modes of communication and representation (oral, graphic, textual).

Teacher Workshops. During their respective first year of participation, third-grade teachers attended four full-day workshops during regular school days throughout the year, fourth-grade teachers attended six full-day workshops including three-day summer workshops, and fifth-grade teachers attended seven full-day workshops including three-day summer workshops. Third-grade teachers attended fewer workshops due to a delay in funding, whereas fifth-grade teachers attended more workshops in response to the new statewide science assessment being administered at fifth grade.

The workshops highlighted improving teachers' knowledge and practices in science instruction and English language development for ELL students. First, the workshops focused on familiarizing teachers with science content, common students' misconceptions about science, potential learning difficulties, and distinctions between hands-on science and science inquiry. Specifically, project personnel and teachers discussed the nature of science inquiry (NRC, 2000) and the teacher-explicit to student-initiated continuum to promote more student-centered and open-ended inquiry (Lee, 2002). Another area of emphasis involved scientific reasoning of students and teachers' reflections on student reasoning.

Second, the workshops focused on incorporating English language and literacy development into specific science lessons. Project personnel described various strategies for developing students' reading and writing skills. They also described how to provide linguistic scaffolding for ELL students. Additionally, teachers worked in small groups to incorporate ESOL strategies in selected lessons from respective units at each grade level.

Instruments and Data Collection

The teachers were observed using scales adapted from our previous research on science instruction (Lee, Hart, Cuevas, & Enders, 2004; Newmann, Secada, & Wehlage, 1995) and English language and literacy development in science instruction (Hart & Lee, 2003), as well as relevant literature. These observation scales are based on a 5-point rating system. In addition to quantitative ratings of teaching practices during specific lessons, observers produced extensive narrative field notes and justifications for their ratings.

The classroom observation guideline included the following scales:

1. *Teacher knowledge of science content* — How accurate and comprehensive is the teacher's mastery of the science content of the lesson?
2. *Scientific understanding* — To what extent do students demonstrate a deep understanding of science?
3. *Scientific inquiry* — To what extent do students engage in scientific inquiry?
4. *Teacher support of English language development* — To what extent do teachers support students' comprehension of science content and development of English language?
5. *Student initiatives* — How many and what kinds of initiatives did students demonstrate? (see Appendix for the scale and ratings)

The *teacher knowledge of science content* and *teacher support of English language development* scales focus on teacher practices, whereas the *scientific understanding* and *scientific inquiry* scales measure the instructional environment that the teacher and students jointly create. For this study, student initiatives were operationalized as unsolicited comments made by students that were directed at the teacher or the class in general. They did not include student responses to questions posed by the teacher. If a student raised his/her hand and was called upon by the teacher, this was counted as an initiative only if the hand raising was not solicited by the teacher. Students' unsolicited comments may have had nothing to do with the science lesson, for example, "Miss X, Johnny wrote on my paper!" or "Can I sharpen my pencil?" For the purposes of this scale, only those comments relating to the science lesson were considered "student initiatives." The issue of whether the student comment was scientifically correct or not did *not* affect its status as a student initiative. Student initiatives fell into three distinct categories (and examples are provided in the Results section and Appendix):

Procedural — questions regarding the procedures of the science lesson

Factual — questions regarding the factual content of the lesson

Conceptual — questions going beyond simple factual content to clarify, elaborate, or explain underlying science concepts

Prior to the classroom observations, project members participated in reliability training using the observation scales to rate videotaped lessons from our previous research. These project members continued training by observing lessons in real time and rating them using the observation scales until they established interrater agreement of over 90%. Prior to conducting the second round of observations, the members repeated the same training procedures.

Each teacher at each grade level was observed once in fall and once in spring. For third grade, fall observations were generally conducted during the measurement unit and spring observations during the water cycle and weather unit. For fourth grade, fall observations were generally conducted during the energy unit and spring observations during the processes of life unit. For fifth grade, fall observations were generally conducted during the earth systems unit and spring observations during the synthesis unit. Each observation typically lasted from 45 minutes to an hour.

Data Analysis

Data analysis was based on 33 third-grade, 21 fourth-grade, and 16 fifth-grade teachers, a total of 70 teachers, as described earlier. The data source included a total of 140 classroom observations. Field notes were color-coded for episodes that illustrated reform-oriented practices for each of the five scales under investigation. For the four scales examining teacher knowledge and practices of teaching science to ELL students, a rating was given ranging from 1 (lowest) to 5 (highest) based on two criteria: (a) the frequency or intensity of reform-oriented practices and (b) the percentage of students who were engaged in such practices. In addition to the ratings for each scale, justifications were provided based on the evidence in the field notes of the lesson.

For the student initiatives scale (Research Question 1), the frequency of initiatives was counted for each of the three categories: (1) procedural, (2) factual, and (3) conceptual initiatives (see Appendix). Then, student initiatives during each lesson were rated based on the combination of the frequency and quality of initiatives.

After a series of meetings among the observers to discuss observation ratings, they paired up to cross-validate each other's ratings to ensure reliability. Each partner rated approximately a half-dozen field notes, and the process continued until 90% agreement was reached. Partners consulted each other when questions about ratings arose. In rare occasions when partners could not reach agreement, the arbiter who oversaw the entire observation rating process intervened until agreements were reached.

At each grade level, means of the ratings for the scales were computed for fall and spring observations separately. The fall and spring data were not combined because of possible differences based on the various science topics taught between fall and spring; these differences might be overlooked if the two time points were collapsed.

The data were collected as students advanced from third to fifth grade for three years in succession. Theoretically, the third-grade students during the first year would continue their participation in the two subsequent years, allowing a longitudinal analysis of change in the frequency of each type of initiative over the three-year period. However, the high mobility of students in these schools (ranging from 27% to 35% based on the school district data) made such analysis problematic, as did the variability of the science topics presented at each grade level. As a result, the study did not conduct a longitudinal analysis or examine grade differences.

To examine the relationship between student initiatives and each of the other four domains of classroom practices (Research Question 2), Pearson correlations were conducted. For each grade level, the means of the observation ratings for fall each year were intercorrelated, and those for spring each year were intercorrelated. Both the coefficients and significance levels are reported. To visually inspect the data for a linear trend, scatter plots were examined for variables that were significantly correlated.

Results

We begin by providing illustrations of student initiatives. The following example is from observations taken with a fifth grade class in the spring of 2007. The class was engaged in a lesson on friction and inertia, with students blowing marbles across different types of surfaces. Initiatives are italicized and the type of initiative is identified with bracket marks. Below, the teacher is giving directions for how to set up the experiment:

T: OK, now lay your sandpaper on the floor next to the ruler. That's not next to, that's on top of.

G: *At the number zero? [Procedural Initiative]*

T: Yes.

A little later, the teacher is still giving directions:

T: Use the same amount of breath that you used last time.

G: *It's not moving! [Factual Initiative]*

Toward the end of the lesson, the class is discussing the meaning of what happened:

T: Thank you. Good. There are bumps and ridges on the floor and the shoes, so that we can walk around. Would that be true if we were on roller skates?

SS: No.

T: That's why we don't have roller skates here.

B: *What would happen if we had no friction on our shoes? [Conceptual Initiative]*

T: Then you'd be walking like you do when you have your new shoes on Easter Sunday. You're slipping and sliding!

We examined the frequency of each type of initiative that students exhibited during each observed lesson (Research Question 1). Table 2 presents the means and standard deviations of the frequency of each type of initiative (i.e., procedural, factual, and conceptual), frequencies of total initiatives, and ratings of total initiatives.

The frequency mean of total initiatives across the three grades for both fall and spring was 3.2. This result indicated that only 3.2 initiatives on average were observed during each lesson. The frequency means of initiatives across grades and semesters ranged from 2.0 to 4.4. There was variability among the three grades, in that grade 5 had the highest frequency of initiatives (3.1 for fall and 4.4 for spring), followed by grade 3 (2.9 for fall and 4.2 for spring), and finally by grade 4 (2.0 for fall and 2.5 for spring). There was also variability between the two semesters, in that more initiatives were observed for spring than fall across all three grades.

Among the three types of initiatives, factual initiatives (1.5) were more frequently observed than procedural initiatives (0.9) or conceptual initiatives (0.9) during each observation across the three grades and across fall and spring. The frequency mean of factual initiatives ranged from 0.8 to 2.6 per grade and per semester. The frequency mean of procedural

Table 2
Means of Frequencies and Ratings of Student Initiatives per Observation

Grade	Year	Term	*n*	Procedural Initiatives *M (SD)*	Factual Initiatives *M (SD)*	Conceptual Initiatives *M (SD)*	Total Initiatives *M (SD)*	Total Initiative Ratings *M (SD)*
3	1	Fall	33	0.6 (0.8)	1.9 (2.7)	0.4 (1.6)	2.9 (3.4)	2.1 (1.0)
3	1	Spring	33	1.4 (1.8)	1.1 (1.9)	1.7 (3.0)	4.2 (4.5)	2.7 (1.2)
4	2	Fall	21	0.7 (1.2)	1.0 (1.3)	0.4 (0.7)	2.0 (2.3)	2.1 (1.0)
4	2	Spring	21	0.8 (1.6)	0.8 (0.9)	1.1 (1.9)	2.5 (2.9)	2.3 (1.1)
5	3	Fall	16	0.8 (1.2)	1.8 (2.6)	0.6 (1.2)	3.1 (3.0)	2.4 (1.0)
5	3	Spring	16	0.8 (0.8)	2.6 (2.9)	1.1 (1.2)	4.4 (3.8)	2.9 (1.1)
Total				0.9 (0.9)	1.5 (1.8)	0.9 (1.6)	3.2 (2.9)	2.4 (0.9)

initiatives ranged from 0.6 to 1.4. The frequency mean of conceptual initiatives ranged from 0.4 to 1.7.

The mean of the total initiative ratings across the three grades for both fall and spring was 2.4. This result indicated that few initiatives (two to four) were observed during each lesson, and these were limited to the procedural and/or factual (see Rating Scale in Appendix). The means of initiative ratings across grades and semesters ranged from 2.1 to 2.9. There was variability among the three grades, in that grade 5 had the highest mean of initiative ratings (2.4 for fall and 2.9 for spring), followed by grade 3 (2.1 for fall and 2.7 for spring), and finally by grade 4 (2.1 for fall and 2.3 for spring). There was also variability between the two semesters, in that higher initiative ratings were observed for spring than fall across all three grades.

Patterns of the results using the frequency and quality (i.e., factual, procedural, and conceptual) of initiatives were consistent with the results using the initiative ratings. Such consistency was expected since the initiative ratings were based on the combination of the frequency and quality of initiatives (see Appendix).

The results about the relationships of student initiatives to each of the four other domains of classroom practices under investigation (Research Question 2) are presented in Table 3. There was noticeable variability across the three grades. For grades 3 and 4, student initiatives were not significantly related to the four other domains of classroom practices across fall and spring, with the exception of practices to promote scientific understanding for grade 3 in fall and practices to promote scientific inquiry for grade 4 in spring. For grade 5, in contrast, student initiatives were significantly related to all the other domains of classroom practices across fall and spring, with the exception of teacher knowledge in spring. Furthermore, the magnitudes of relationships were higher for grade 5. Across all three grades, there was no discernable variability across fall and spring.

Discussion and Implications

This study examined the frequency and quality of initiatives that third-, fourth-, and fifth-grade ELL students made while they participated in inquiry-based science instruction to promote science learning and English language development (Research Question 1). The results indicated that the frequency of student initiatives was low, with an average of 3.2 initiatives during each observation across three grades and across fall and spring. The quality of student initiatives was also low, with factual initiatives being more frequent than procedural or conceptual initiatives.

Four sets of results are noteworthy in the context of our intervention. First, the overall low numbers with respect to quantity and quality of student initiatives are consistent with the literature indicating few student initiatives in science classrooms (Edwards & Mercer, 1987; Lemke, 1990; Rop, 2002). Second, the elementary students in this study, many of whom were ELL students, did offer some initiatives, despite the fact that they might have faced additional challenges linguistically and culturally (McKinley, 2007;

Table 3
Relationships of Student Initiatives to Other Domains of Classroom Practices

Grade	Year	Term	*n*	Initiatives	Teacher Knowledge	Understanding	Inquiry	English Language Development
				r	*r*	*r*	*r*	*r*
3	1	Fall	33	—	—	0.37*	—	—
3	1	Spring	33	—	—	—	—	—
4	2	Fall	21	—	—	—	—	—
4	2	Spring	21	—	—	—	0.46*	—
5	3	Fall	16	—	0.73**	0.56*	0.76**	0.64**
5	3	Spring	16	—	—	0.59*	0.53*	0.65**

Note. Only significant Pearson coefficients (significance level <0.05) are shown.
* $p < 0.05$; ** $p < 0.01$

Nelson-Barber & Estrin, 1995; Rogoff, 1990; Solano-Flores & Nelson-Barber, 2001). Third, the frequency and quality of student initiatives were consistently higher in spring than fall across all three grades. This result indicates that within each grade, students made more initiatives as the school year progressed. Finally, the frequency of student initiatives was higher for grade 5 than those for grades 3 and 4. It could be that students developed an understanding of making initiatives as they continued participation for three consecutive years in the intervention; however, this possibility is limited by the mobility issue previously discussed.

This study also examined whether student initiatives were related to other domains of classroom practices, including teacher knowledge of science content, teaching science for understanding, teaching science for inquiry, and teacher support for English language development (Research Question 2). For grades 3 and 4, student initiatives were generally not related to these other domains, whereas student initiatives were significantly related to almost all the other domains for grade 5.

The literature suggests that student initiatives are related to other domains of classroom practices (Lee, 2002; NRC, 2000; Rosebery et al., 1992). This appeared to be the case with the fifth grade data that showed positive, significant relationships between student initiatives and other domains of classroom practices. In other words, fifth-grade students made more initiatives in classrooms where teachers showed better knowledge of science content or who better promoted students' scientific understanding, inquiry, or English language development. In contrast, there were no significant relationships between student initiatives and other domains of classroom practices for grades 3 and 4.

For both research questions, differences by grade levels are to be noted. There are several possible reasons for both the higher frequency of initiatives and more significant relationships for grade 5. As discussed above, fifth-grade students might have developed an understanding of making initiatives as they continued participation in the intervention. However, this conjecture could not be tested due to high student mobility and the difficulty of identifying students across classrooms over the three-year period. Additionally, given high-stakes testing and accountability in science at grade 5, science instruction was often departmentalized. It could be that fifth-grade teachers might have better knowledge of science and provided more effective teaching practices than third- and fourth-grade teachers. Provided with such learning environments, fifth-grade students exhibited initiatives more frequently.

The results of the study provide insights for our ongoing professional development and similar efforts. Considering their first-year participation in our intervention, teachers might not yet have acquired sufficient science knowledge presented in our curriculum or teaching practices to promote student initiatives. While lack of science knowledge is often cited as a reason for ineffective science instruction, the

extensive professional development in our intervention may lead to improved teacher knowledge of science content as well as teacher support of student initiatives. For example, based on classroom observations during the first year of our intervention, workshop facilitators discussed "missed opportunities" in which teachers could have promoted students' scientific inquiry and understanding through teacher questioning, student reasoning, and class argumentation. Additionally, workshop facilitators emphasized the importance of scaffolding students-centered and open-ended inquiry (NRC, 2000).

The results suggest areas for future research. This study addressed both methodological and theoretical issues to examinc the quantity and quality of student initiatives. It also examined how student initiatives were related to other domains of science classroom practices. We will examine these questions at the completion of our five-year intervention. We will test the hypothesis that as teachers become more knowledgeable of science content and improve teaching practices, students will have a better understanding of initiatives and exhibit initiatives more frequently. The improvement in both the frequency and quality of initiatives will, in turn, improve science achievement of all students, including ELL students.

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Authors' Notes

This work is supported by the National Science Foundation (NSF Grant #ESI–0353331). Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the position, policy, or endorsement of the funding agencies.

The authors acknowledge the valuable feedback from Jane Sinagub.

Appendix

Student Initiative

How many and what kinds of initiatives did students demonstrate?

This scale is designed to measure the extent to which students take the initiative in determining the direction of science-related activities and discussions. Scientific understanding and inquiry require students to go beyond simply following a procedural recipe or registering information transmitted by the teacher or text. While paying attention, listening, observing, and being engaged are important elements of science learning and not all students will be equally active in the development of a lesson, student passivity should not be the general rule. There should be evidence that students are assuming some responsibility for their independent learning, rather than being completely dependent on the teacher. Students' initiative is an indication that they are truly beginning to participate as members of a science learning community. Absence of initiative could indicate that students are disengaged from the lesson or that the teacher has near-absolute control of classroom discourse. For example, if students are not allowed to speak unless they are called upon to do so, the teacher controls the lesson and students have no opportunities to take the initiative in their own learning.

The term "student initiative" refers to unelicited comments by students that are directed at the teacher or the class in general. They do not include student responses to questions posed by the teacher. If a student raises his/her hand and is called upon by the teacher, this counts as an initiative only if the hand-raising is not solicited by the teacher. Many of students' unsolicited comments may have nothing to do with the science lesson, for example, "Miss X, Johnny wrote on my paper!" or "Can I sharpen my pencil?" For the purposes of this scale, only those comments relating to the science lesson will be considered "student initiatives." These fall into three distinct categories:

Procedural: student initiatives that refer to the procedures of the science lesson. Examples: "You have to read the graduated cylinder at eye level." "Where on the chart do I write my answer?"

Factual: student initiatives related to the factual content of the lesson. Examples: "Mine says 78 degrees." "At what temperature does water boil?" "I know the names of the nine planets."

Conceptual: student initiatives that go beyond simple factual content to clarify, elaborate, or question underlying science concepts. Examples: "If gasoline is a liquid, why is it called 'gas'?" "Air isn't matter 'cause it doesn't weigh." "When the bathroom mirror fogs up, is that condensation?" "Tornados are just like hurricanes except they're smaller."

A lesson is scored high on this scale when many students take initiatives, including some conceptual initiatives. In contrast, a lesson is scored low when student initiatives are infrequent and are limited to the procedural and factual.

Note: The issue of whether the student comment is scientifically correct or not does *not* affect its status as a student initiative. This scale measures *student* behavior; the teacher's response to student initiatives should not directly affect the score (though it probably will affect students' willingness to initiate), but should be noted in the description of the lesson.

An accurate measure of student initiatives requires that the description of the lesson be sufficiently detailed as to capture all those that occur. If the observer is unable to register the exact content and wording of all student initiatives, he/she should capture the general content or meaning of the initiatives.

Rating Scale

1. No student initiatives are observed.
2. Very few student initiatives (1-3) are observed, and these are limited to the procedural and/or factual. OR, there are more than several procedural and/or factual initiatives (3 or more), but they all come from 1 or 2 students.

3. Several student initiatives (4 ore more) are observed, and they are distributed among several students (10-20%) OR there are very few student initiatives (1-3), but some of these are conceptual.

4. Many students (20-50%) offer initiatives, including some conceptual (1-3) ones.

5. Many students (20-50%) offer initiatives, and several of these (4 or more) are conceptual. Student initiatives play a significant role in directing class discussion and activity.

Problems section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972-86-477-648. Questions concerning proposals and/or solutions can be sent e-mail to <eisenbt@013.net>. Solutions to previously stated problems can be seen at <http://ssmj.tamu.edu>.

Solutions to the problems stated in this issue should be posted before May 15, 2010

• **5104:** *Proposed by Kenneth Korbin, New York, NY*

There are infinitely many primitive Pythagorean triangles with hypotenuse of the form $4x^4 + 1$ where x is a positive integer. Find the dimensions of all such triangles in which at least one of the sides has prime integer length.

• **5105:** *Proposed by Kenneth Korbin, New York, NY*

Solve the equation

$$x + y - \sqrt{x^2 + xy + y^2} = 2 + \sqrt{5}$$

if x and y are of the form $a + b\sqrt{5}$ where a and b are positive integers.

• **5106:** *Proposed by Michael Brozinsky, Central Islip, NY*

Let a, b, and c be the sides of an acute-angled triangle ABC. Let H be the orthocenter and let d_a, d_b and d_c be the distances from H to the sides BC, CA, and AB respectively. Show that

$$d_a + d_b + d_c \le \frac{3}{4} D$$

where D is the diameter of the circumcircle.

• **5107:** *Proposed by Tuan Le (student, Fairmont High School), Anaheim, CA*

Let a, b, c be positive real numbers. Prove that

$$\frac{\sqrt{a^3 + b^3}}{a^2 + b^2} + \frac{\sqrt{b^3 + c^3}}{b^2 + c^2} + \frac{\sqrt{c^3 + a^3}}{c^2 + a^2} \ge \frac{6(ab + bc + ac)}{(a + b + c)\sqrt{(a + b)(b + c)(c + a)}}.$$

• **5108:** *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

Compute

$$\lim_{n \to \infty} \frac{1}{n} \tan\left[\sum_{k=1}^{4n+1} \arctan\left(1 + \frac{2}{k(k+1)}\right)\right].$$

• **5109:** *Proposed by Ovidiu Furdui, Cluj, Romania*

Let $k \ge 1$ be a natural number. Find the value of

$$\lim_{n \to \infty} \frac{\left(k\sqrt[n]{n} - k + 1\right)^n}{n^k}.$$

EDUCATIONAL MEASUREMENT: ISSUES AND PRACTICE

Edited by
SUSAN M. BROOKHART

Published on behalf of the National Council on Measurement in Education

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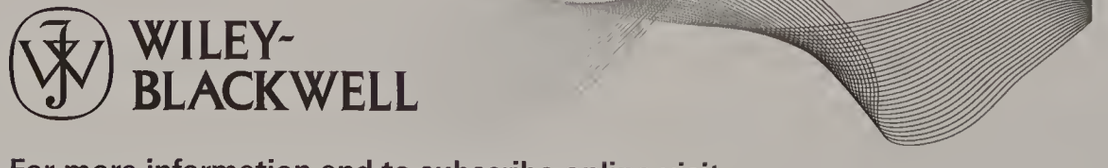

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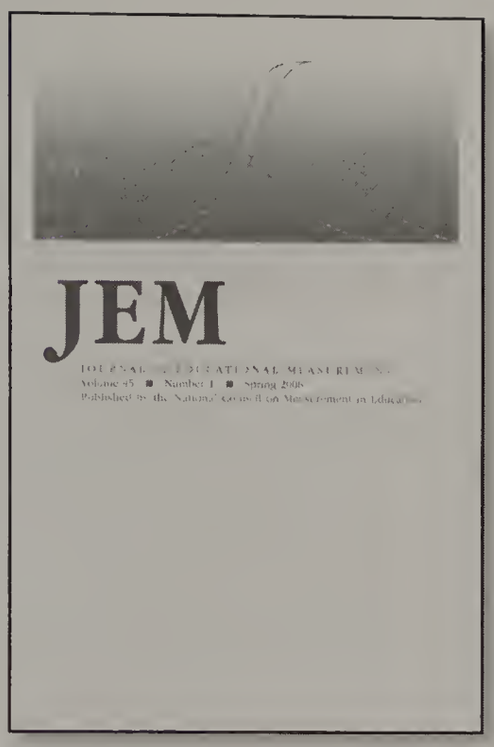

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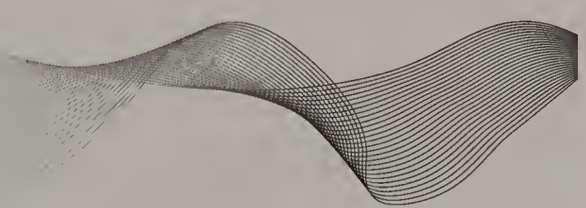

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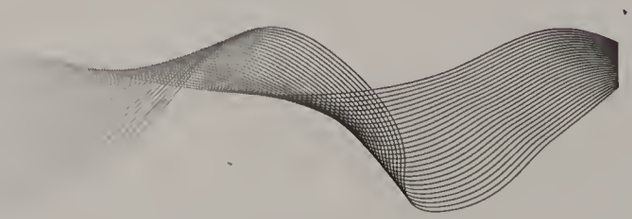

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Frequency of issue: 8 times per year
Copies per issue: 3001-4000
Sponsorship: Professional organization

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School Science and Mathematics (Print ISSN: 0036-6803, Online ISSN: 1949-8594) is published in January, February, March, April, September, October, November and December on behalf of the School Science and Mathematics Association by Wiley Subscription Services, Inc., a Wiley Company, 111 River St., Hoboken, NJ, 07030-5774. Periodical postage paid at Hoboken, NJ and additional offices.

Postmaster: Send all address changes to *School Science and Mathematics*, Journal Customer Services, John Wiley & Sons, Inc., 350 Main St., Malden, MA 02148-5020.

Information for Subscribers: *School Science and Mathematics* is published in eight issues per year. Subscription prices for 2010 are: Institutional Print & Online rate: US$250 (the Americas), US$250 (Rest of World), €180 (Europe) £153 (UK). Prices are exclusive of tax. Asia-Pacific GST, Canadian GST and European VAT will be applied at the appropriate rates. For more information on current tax rates, please go to www3.interscience.wiley.com/aboutus/journal_ordering_and_payment.html#Tax. The institutional price includes online access to the current and all online back files to January 1, 1997, where available. For other pricing options, including access information and terms and conditions, please visit www.interscience.wiley.com/journal-info.

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ISSN: 0036-6803 (Print)
ISSN: 1949-8594 (Online)
Printed in the US by The Sheridan Group.

IN THIS issue

Research in Brief

Teachers' Interactions with Curriculum Materials in Mathematics

Ilham Elsaleh

Textbooks are curriculum materials used for guiding students' acquisition of certain culturally valued concepts, procedures, intellectual dispositions, and ways of reasoning (Battista & Clements, 2000). Textbooks are the physical resource for students' performance in the classrooms. The evaluation results from The Third International Mathematics and Science Study have shown that the curriculum materials have positively affected the middle-school students' performance (Schmidt, McKnight, & Raizen, 1997). Despite the variation of the enacted curriculum, students' achievement was related to the defined quality of the textbooks (Klum & Capraro, 2004). For that reason, the curriculum materials are getting more attention in the recent studies. United States educational accountability calls for extensive research in measuring student outcomes related to mathematics curriculum programs (Lloyd, 2009; National Research Council, 2004; Senk & Thompson, 2003).

Research Articles

Validation of the Diagnostic Teacher Assessment of Mathematics and Science (DTAMS) Instrument

Jon Saderholm, Robert Ronau, E. Todd Brown, Gary Collins

The Diagnostic Teacher Assessment in Mathematics and Science (DTAMS) Instrument was developed to measure the content knowledge and pedagogical content knowledge of middle-school teachers. Its reliability and validity were initially established by reviewing national standards for content and use of expert question writing teams and reviewers. DTAMS was administered to approximately 1,600 middle-school mathematics teachers in 17 states. Subsequent analyses using structural equation modeling and item response theory were performed as part of a multistage validation process. This evaluation contributes to the body of work describing the reliability and validity of these assessments. The results of this study confirm trends in middle-school mathematics teacher preparation and certification, and help explain middle-school student mathematics achievement levels.

Changes in Teaching Efficacy during a Professional Development School-Based Science Methods Course

Susan L. Swars, Caitlin McMunn Dooley

This mixed-methods study offers a theoretically grounded description of a field-based science methods course within a Professional Development School (PDS) model (i.e., PDS-based course). The preservice teachers' (n = 21) experiences within the PDS-based course prompted significant changes in their personal teaching efficacy, with the opportunities working with children afforded in the course attributed as a source of these beliefs. However, the preservice teachers' teaching outcome expectancy beliefs did not significantly shift. The results of this study support the extant literature in that field experiences with science methods courses can facilitate preservice teacher development in meaningful ways. This study expands upon this literature by considering a PDS context for science teacher preparation, more specifically, a science methods course purposefully integrated in elementary classrooms at a PDS where preservice teachers facilitated scientific inquiry projects with children. The findings should prompt new ways of thinking about teacher preparation, particularly related to science, that provide systematic and intentional connectivity between university programs and K-12 schools so preservice teachers can connect theory and practice.

A Partnership Approach to Improving Student Attitudes About Sharks and Scientists

Kanesa Duncan Seraphin

This article describes the methods and impact of a student-teacher-scientist research partnership on student attitudes. The partnership objective was to teach students about the diverse roles of sharks in the marine environment while personally connecting students with scientific study. Students (N = 229) participated in lessons about shark biology and helped the partnering scientist design experimental protocols and analyze data. A self-selected subset of students also volunteered (n = 82) for a field component working

with live hammerhead sharks (*Sphyrna lewinii*).Student surveys before and after the partnership suggested that negative attitudes about sharks are due largely to lack of exposure, and direct attention to students' stereotypes about sharks resulted in significant attitude improvement. Change in students' attitudes toward scientists, however, was minimal. Students' negative views of scientists did decline significantly, but their overall views of scientists were relatively positive to begin with. Also of interest were the students' unremitting association of scientists with specialized equipment and the students' lack of personal connection to scientific ways of examining the world, suggesting that partnerships may be more effective at personally connecting students with scientific process if they explicitly incorporate activities designed to improve students' view of themselves as scientists.

Development and Validation of a Computer-Administered Number Sense Scale for 5th-Grade Children in Taiwan

Mao-Neng Fred Li, Der-Ching Yang

To investigate the structure of number sense and then to assess its uses in fifth-grade children's number sense development, a computerized number sense scale was developed and evaluated. The findings of the study indicate that the newly developed scale, with four dominant factors identified and reconfirmed, is internally consistent and substantially valid. It can be reliably used as a screening measure for a quick check of students' number sense development via online self-assessment. Compared with our previous study (Yang, Li, & Li, 2008), both qualitative and quantitative changes were detected in students' number sense development at different grades. The qualitative change in number sense development is manifested in a number of factor components produced at different grades. The quantitative change is manifested in the amount of factor variance explained at different grades. Futhermore, among the four aspects of number sense, Taiwanese students perform best on "recognizing the relative number size"; yet, relatively worse on "judging the reasonableness of computational results."

Ilham Elsaleh
Texas A&M University

Teachers' Interactions with Curriculum Materials in Mathematics

Textbooks are a key part of curriculum materials used for guiding students' acquisition of certain culturally valued concepts, procedures, intellectual dispositions, and ways of reasoning (Battista & Clements, 2000). Textbooks are also often the primary resource for students and teachers in the classroom. For some teachers, textbooks act as prepared courses by providing them with explanations, classroom discussion techniques, reflections about students' mathematical thinking, and specific examples of students' errors or misconceptions. There are many reasons for teachers' heavy reliance on textbooks, including both efficiency in preparation and ease of use (Schug, Western, & Enochs, 1997). The evaluation results from The Third International Mathematics and Science Study showed that curriculum materials have significant effects on middle-school students' mathematics performance (Schmidt, McKnight, & Raizen, 1997). In a study of middle-grades teachers, Kulm and Capraro (2008) found that despite the variation of the enactment, students' achievement was significantly related to the defined quality of the textbooks. United States educational policymakers, in calling for increased accountability, have encouraged extensive research in measuring student achievement as outcomes of mathematics curriculum programs (Lloyd, Remillard, & Herbel-Eisenmann, 2009; National Research Council [NRC], 2004; Senk & Thompson, 2003). The NRC found that there is insufficient evidence of the effectiveness of any of the present standards-based curriculum materials "due to the restricted number of studies for any particular curriculum, limitations in the array of method used, and the uneven quality of the studies" (NRC, p. 3). The NRC recommended that the quality teachers' implementation of curriculum should be included in future research.

The reform efforts in mathematics education resulted in curriculum development based on the standards of the National Council of Teachers of Mathematics (1989, 2000). Teachers are sometimes challenged by the demands of these curriculum materials in which new conceptual and pedagogical approaches are required. Standard-based curricula require teachers to use questions at high cognitive levels, to emphasize conceptual understanding, and to connect mathematical ideas. These new curricula have generated many questions about their mathematics and pedagogical content (Reys, 2001) and teachers' knowledge (e.g., An, Kulm & Wu, 2004; Ma, 1999). Because teachers are critical agents for bringing changes into their classrooms (Doyle & Ponder, 1977; Fullan, 1982; Gross, Giacquinta, & Bernstein, 1971), the successes and barriers experienced by teachers should be a major source of evidence for assessing the impact of curriculum on students' learning. For example, Manouchehri and Goodman (2000) examined teachers' reactions to standard-based mathematics textbooks and found that the changes in teachers' practices do not happen automatically; teachers did not change their teaching practices merely by being exposed to the innovative materials. The results of this qualitative study suggested that the teachers should be guided and supported in their pedagogical approaches. The study supports the belief that teachers need training in order to implement the vision of reform materials.

There are many contextual and social factors that influence the ways teachers engage with and use curriculum materials in their teaching. The way that teachers use textbooks is affected by their individual teaching philosophies and practices. Eisner (1987) stated that textbooks not only define a substantial proportion of the content, sequence, and aims of the curriculum, but also they affect the way in which certain topics will be taught. Some teachers make adaptations to the lessons, supplement the lessons with additional activities, or omit the whole lesson. Teachers' years of experience affect their conceptions

of how to implement newly adopted textbooks (Christou, Eliophotou-Menton, & Philippou, 2004). Since teachers are usually given the freedom of using or not using the adopted textbooks of their districts, the majority of teachers do use the district-adopted textbook as their main source of teaching. Grouws and Cebulla (2000) have reported that about two-thirds of teachers use the textbooks almost every day. However, many teachers decline the use of the textbooks and prefer to use worksheets and other materials that they develop or select.

The role of curriculum materials in teacher education and professional development is often overlooked. Textbooks and their use have the potential to shape the pedagogical and the content knowledge of teachers. Davis and Krajcik (2005) recognized that researchers recently began to focus on the teacher component and to explore the role of curriculum materials in teachers' learning. The path toward becoming a teacher can be viewed as a process of socialization (Gregg, 1995; Zeichner & Gore, 1989). Such processes take place within relationships and contextual elements that include the people, programs, and settings within which learning to becoming a teacher takes place (Feiman-Nemser & Buchmann 1987; Zeichner, 1985). The interaction with curriculum materials is an important source of teachers' learning (Leikin, 2006). When the teachers plan for lessons, they express the need to know the content of the textbook well enough in order to teach. In this way, the textbook stimulates teachers' thinking.

Research on teachers' interactions with textbooks can provide valuable insights and the potential for curriculum materials to contribute to reform in mathematics teaching. Mathematics education is at the intersection between two trends; (1) the availability and the implementation of newly designed curriculum materials and (2) the schools' tendency to use and mandate a single curriculum in order to regulate mathematics' teaching practices (Remillard, 2005). In that regard, using a high-quality textbook in every classroom could be an effective way to enhance teaching practice and further develop the curriculum. Reducing the variables in this complex equation is part of the solution to reform. The variables that affect improved teaching quality are easier to control when all teachers use a high-quality textbook. The issue of teachers' use of textbooks has rarely been approached with care and creativity (Ball & Cohen, 1996). Understanding the critical relation between the teacher and the intended curriculum as well as the role of high-quality mathematics textbooks on students' performance has the potential for impact on student learning.

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Validation of the Diagnostic Teacher Assessment of Mathematics and Science (DTAMS) Instrument

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The Diagnostic Teacher Assessment in Mathematics and Science (DTAMS) was developed to measure the content knowledge and pedagogical content knowledge of middle-school teachers. Its reliability and validity were initially established by reviewing national standards for content and use of expert question writing teams and reviewers. DTAMS was administered to approximately 1,600 middle-school mathematics teachers in 17 states. Subsequent analyses using structural equation modeling and item response theory were performed as part of a multistage validation process. This evaluation contributes to the body of work describing the reliability and validity of these assessments. The results of this study confirm trends in middle-school mathematics teacher preparation and certification and help explain middle-school student mathematics achievement levels.

The purpose of the following study was to examine more closely the depth and breadth of teacher's mathematical knowledge. This study occurred in the context of the development of the Diagnostic Teacher Assessment in Mathematics and Science (DTAMS) mathematics assessments for middle-school teachers which were designed to (1) align with content defined by national documents, (2) be of useful length, (3) assess both breadth and depth of mathematics content, (4) address misconceptions found in research literature, and (5) be valid and reliable. This article shares the process of determination of the validity and reliability of this set of instruments for middle-school mathematics teachers, and shares the diagnostic results and test scores of 1,600 teachers who participated in the field study of the DTAMS mathematics assessments. Our intention was not only to evaluate the instruments, but also to gather data describing a preliminary level of performance. The goal of this study is to inform teacher education institutions, professional development providers and other educational providers what mathematics learning prospective and practicing teachers required to be able to provide the highest level of mathematics instruction.

Over the previous 40 years, increasing attention has been paid to the impact of teacher characteristics on student achievement (Coleman, Campbell, Hobson, McPartland, Mood, Weinfeld, & York, 1966). A significant body of research on teacher's mathematical knowledge exists, but as the National Research Council ([NRC], 2001) report *Adding It Up* found, this body of work was based on measures that did not provide a clear picture of what mathematics teachers knew. Teacher subject matter preparation, particularly in mathematics, is related to student achievement even after controlling for teacher and student background characteristics such as race/ethnicity and socioeconomic status (Darling-Hammond, 2000). Most frequently, teacher subject matter preparation was operationalized as the number of mathematics courses their teacher had taken (Begle, 1979; Miller, Kimmel, Hoffer, & Nelson, 2000; Reese, Miller, Mazzeo, & Dossey, 1997). But, as noted in *Adding It Up*, ". . . the topics taught in upper- level mathematics courses are often remote from the core content of the K-12 curriculum" (NRC, p. 375). The report recommends investigating with more sensitivity the mathematical knowledge needed to teach.

Background

Since the publication of the *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics [NCTM], 1989), mathematics curricula in elementary and middle schools in the United States have changed dramatically. These initial standards and the later NCTM

(2000) *Principles and Standards for School Mathematics* recommended important mathematics that students need to be productive citizens. The standards also stress balanced mathematics teaching that emphasizes mathematical proficiency (NRC, 2001), the importance of teaching for conceptual understanding, problem solving, and reasoning. The standards expand the variety of mathematics content and increase the depth of understanding at which it must be learned. In order to provide this instruction, qualified instructors must possess the skills and abilities to provide these learning opportunities.

The curriculum shift toward deeper understanding increases the mathematical demands on middle-grades teachers. The *Professional Teaching Standards* (NCTM, 1991) suggest that teachers need to have a broader and deeper knowledge of mathematics in number theory, geometry, measurement, algebra, probability, and statistics. Teachers are expected to provide fundamental understandings and models for all students to be successful (NRC, 2001). Teacher knowledge frameworks can be exemplified by Shulman (1986), who defined pedagogical content knowledge (*PCK*) as a particular form of content knowledge that embodies the aspect of content most germane to its teachability. "It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8). Ball (1988, 1995, 1996) delineated the importance of teacher subject matter knowledge on student achievement. Then, Hill, Schilling, and Ball (2004) developed a measure for assessing mathematical content knowledge for teaching. Marks' (1990) framework included four realms of *PCK*: subject matter, students' understandings, media, and instructional processes and Graeber's (1999) framework based teacher training methodology for *PCK* based upon misconceptions, intuition, and conceptual understanding. Capraro, Capraro, Parker, Kulm, and Raulerson (2002, 2005) posited a framework that focused on the role of interaction in the development of *PCK*. Peressini, Borko, Romagnano, Knuth, and Willis (2004) delineated a framework that included the interactions of teacher beliefs and knowledge with situational contexts in the development of teacher knowledge, while Davis and Simmt (2006) combined *PCK* with complexity science to view classrooms as learning systems that are self-organizing, self-maintaining, and adaptive. Mishra and Koehler developed a framework that integrates technology into *PCK* (Koehler & Mishra, 2008; Mishra & Koehler, 2006). Finally, Ronau et al. (2008) posited a framework for teacher knowledge that included levels of field, mode, and context.

Teaching is a knowledge-based activity and teachers must know that some mathematical ideas are more challenging for students to learn. Teachers are expected to provide fundamental understandings and models for all students to be successful (NRC, 2001). And yet schools still have middle-school teachers who have certification without specialization in mathematics. The Mathematical Sciences Education Board (1996) found that 27% of middle-school teachers majored in general education while Lewis et al. (1999) reported that only 44% had an undergraduate or graduate major in an academic field.

Recently, as a consequence of *No Child Left Behind*, teachers, researchers, and policymakers have discussed what mathematics teachers need to know and, as a result, professional organizations have made mathematics content recommendations and proposed standards for teaching (e.g., NCTM, National Board for Professional Teaching Standards, Mathematical Association of America/American Mathematical Society). For example, Praxis I measures a teacher-candidate's knowledge of the subject(s) in which he or she is seeking certification. The passing rate for the mathematics achievement for 1997–2001 was 70%. Currently, all but six of the 50 states (Arizona, Florida, Illinois, Massachusetts, Michigan, and Montana) require teachers to take the Praxis test (Educational Testing Service, 2006). However, to date there are no reliable or valid mathematics assessments other than licensure examinations that capture what teachers know regarding the content they teach. Extensive literature and web-based searches have not revealed any such assessments, with the exception of some recent work on instruments at the University of Michigan that assess elementary teachers' mathematics knowledge necessary for teaching (Hill et al., 2004).

Review of Assessment Development

DTAMS mathematics assessments for middle-school teachers serve two purposes. It describes the breadth and depth of mathematics content knowledge so that researchers and evaluators can determine teacher knowledge growth over time, the effects of particular experiences on teachers' knowledge, or

relationships among teacher content knowledge, teaching practice, and student performance. It also describes the state of middle-school teachers' mathematics knowledge so that teacher educators, school administrators, and teachers can make appropriate decisions with regard to courses, professional development, or acceptance into teacher preparation programs.

Determining Breadth of Content for Middle-School Teachers

To determine breadth of assessable mathematics content for middle-school teachers, teams of mathematicians, mathematics educators, and middle-school teachers conducted literature reviews for the content appropriate for middle-school teachers as defined by national recommendations, standardized tests, and research on misconceptions for both middle-school students and teachers. The documents that were reviewed included the *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989), *Principles and Standards for School Mathematics* (NCTM, 2000), the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993), eighth-grade objectives and items from the National Assessment of Educational Progress, and research on middle-school students' misconceptions and learning deficiencies in mathematics. The teams also reviewed recommendations about middle-school teachers' mathematics knowledge in, for example, the *Professional Standards for Teaching Mathematics* (NCTM, 1992); *The Mathematics Education of Teachers* (Conference Board of the Mathematical Sciences, 2001); *Model Standards in Mathematics for Beginning Teacher Licensing and Development: A Resource for State Dialogue* (Interstate New Teacher Assessment and Support Consortium, 1995) as well as the objectives and released items of the mathematics portions of *Praxis Examination for Teachers* (Educational Testing Service, 2001). Second, teams comprised of mathematicians, mathematics educators, and middle-school teachers created the content charts and the mathematics topics that appeared in more than half of these sources were used to define the breadth of mathematics knowledge assessed by the DTAMS assessments. The teams developed prototype and parallel versions of the assessments. Third, reviewers representing a national geographic cross-section determined the appropriateness of items created for the six versions of each assessment. The 24 instruments were sent to 35 mathematicians, mathematics educators, and middle-school mathematics teachers who responded to a national call for reviewers. For each set of items, reviewers were asked to (1) identify the mathematics content of the item from a list of specific topics (taken from item specification charts), (2) identify the knowledge type (I, II, III, IV), and (3) indicate if the item assessed important mathematics content for middle school teachers (high, medium, or low level of importance). Each of the six versions of all four assessments was reviewed by at least six reviewers, with at least one mathematician, mathematics educator, and teacher reviewing each assessment they recognized the importance of reliable work, but were not trained on what the types represented. An item met initial criteria for inclusion if 60% of the reviewers identified it as assessing a particular content and knowledge type and 75% deemed it appropriate and important knowledge for middle-school teachers. Subsequent reviewer sessions were designed including training about types and domains. After these sessions, agreement increased 80–90%.

Determining Depth of Knowledge for Middle-School Teachers

The depth of mathematics knowledge assessed was based on research defining types of mathematics knowledge. Learning theorists and cognitive scientists like Gagné (1985), Bloom, Engelhart, Hill, Furst, and Krathwohl (1956), Bruner (1960), Piaget (1952/1963), Vygotsky (1978), and Gardner (1983) have offered general models and frameworks for knowledge. These frameworks, however, were derived from and built upon the frameworks and models for general knowledge. Through review of this body of research on mathematics knowledge, we identified four types of knowledge that we considered necessary for teachers of mathematics.

The first type of knowledge is simply that which can be learned through memorization. We call this type of knowledge *declarative knowledge* (Type I, Table 1). The second type of knowledge is characterized by understanding, which Skemp (1971) identified two types of mathematical understanding—*instrumental* and *relational*. *Instrumental understanding* refers to rotely learned knowledge and ideas that are completely isolated from each other. *Relational understanding*, on the other hand, refers to developing meaningful networks of concepts and procedures. Hiebert and Carpenter (1992) later introduced the terms *procedural knowledge* and *conceptual*

Table 1
DTAMS: Number of Items by Type and by Subdomain

Domains and Subdomains	Type I	Type II	Type III	Type IV	Total Items
Algebra					
Functions and patterns	5	5	3	2	15
Expressions and polynomials	1	4	0	2	7
Equations and inequalities	4	1	2	1	8
Total items (algebra)	10	10	5	5	30
Geometry/measurement					
Two-dimensional geometry	3	2	2	0	7
Three-dimensional geometry	2	3	1	3	9
Transformation and coordinates	0	5	1	1	7
Measurement	4	1	1	1	7
Total items (geom/meas)	9	11	5	5	30
Number/computation					
Whole numbers	3	2	3	2	10
Rational numbers	2	3	1	1	7
Integers	2	3	1	1	7
Number theory	4	1	1	0	6
Total items (num/comp)	11	9	6	4	30
Probability/statistics					
Data analysis	5	5	3	2	15
Probability	5	5	2	3	15
Total items (prob/stats)	10	10	5	5	30

knowledge to describe these types of mathematics knowledge. Using connections like Skemp's framework, Hiebert and Carpenter described *procedural knowledge* as a sequence of actions with minimal connections needed to create internal representations of a procedure between succeeding actions.

The second type of knowledge we considered we called *conceptual knowledge*. This type of knowledge is rich in relationships and developed within well-connected conceptual networks (Type II, Table 1). A third type of knowledge evolves from using these first two types in different contexts. This higher-order mathematics knowledge is used during *problem solving* (Polya, 1957; Schoenfeld, 1985) and *reasoning* (NCTM, 1989, 2000). Problem solving requires developing or applying strategies, carrying out strategies, and reflecting upon strategies (metacognition). *Mathematical reasoning* also requires using existing knowledge to reason inductively and deductively with mathematical ideas and to develop other types, like proportional and spatial reasoning (Type III, Table 1). The fourth type of knowledge, conceptualized by Shulman (1986) in his framework of teacher knowledge, is *PCK*. Shulman argued that *PCK* is different from *subject matter knowledge* and that it is critical for teachers because it is specific to the profession and

represents how teachers use their knowledge of mathematics in teaching (Type IV, Table 1). In the DTAMS framework, *PCK* included identifying and correcting student misconceptions and errors, creating analogies and examples to explain procedures and phenomena, and helping students make connections across mathematical concepts and ideas. The four types of knowledge were labeled as Type I (memorization), Type II (conceptual understanding), Type III (higher-order thinking), and Type IV (*PCK*).

Assessments were developed for four content domains: number/computation, geometry/measurement, probability/statistics, and algebraic ideas (domains and subdomains, Table 1). Each assessment measures mathematics knowledge necessary for middle-school teachers and is composed of 20 items—10 multiple-choice and 10 open-response items. Each open-response item has two components; part one assesses the mathematics content needed to solve the problem, while part two assesses either problem-solving skill, or the pedagogical knowledge necessary to address student misconceptions. Six versions of each assessment were constructed and tested for this study.

Development Design for Validity and Reliability

Between May 2005 and March 2006, approximately 3,500 assessments were completed by about 2,300 teachers at 38 sites in 17 states. Some of these teachers completed a single assessment while others completed two or more in a pre/post format. Three types of reliability were determined from the results of these assessments. First, internal reliability was determined by computing internal consistency (Cronbach's alpha) for each of the 24 assessments. Second, equivalency reliability was determined by computing Pearson product moment correlations for pairs of assessments completed by the same teachers. Finally interscorer reliability was established using intraclass correlation coefficients and percentage of agreements among three scorers who evaluated the teacher responses. Values for each of these forms of reliability were greater than .80 and are considered acceptable for basic research (Nunnally, 1978).

Method

Structural Equation Modeling

Confirmatory factor analysis was used to assess the fit of items within each of the separate structures. Separate structural equation models (SEM) were constructed for each test's content subdomain and knowledge type structure. Response patterns were analyzed to identify items that appeared to correlate poorly with the latent factor (content or knowledge type) they were intended to reflect, correlate with another factor, or correlate with multiple factors. Byrne (1998) suggests that due to the complex nature of the analytic process in SEM, changes to a hypothesized model should be made due to model misfit only when a sound theoretical basis exists for the change. Therefore, because each test was the result of an extensive validation process, items that appeared misspecified within their structure were examined with the intention of changing the wording or structure of the item, but not eliminating them or changing their location in the structure.

Each test was designed to measure both content understanding and knowledge type simultaneously. In the first analytic step, to account for this design feature, distinct content domain and knowledge type structures were hypothesized for each subject area test. This was necessary because the knowledge type and content subdomain theoretical structures organized the test items differently, making it impossible to construct a single model based on both structures. LISREL 8.80 (Jöreskog & Sörbom, 2006) was chosen for this analysis because it uses polychoric correlation and covariance matrices that are not sensitive to non-interval data, making it more appropriate for the analysis of this data set. Review of related literature revealed several goodness-of-fit indices are most frequently reported. In the present study, model fit was evaluated using the chi-square value, the comparative fit index (*CFI*) (Bentler, 1990), the root mean square error of approximation (*RMSEA*) (Steiger & Lind, 1980), and the non-normed fit index or Tucker–Lewis Index (*TLI*) (Tucker & Lewis, 1973).

Item Response Theory

Psychometric properties affected how well items measured teacher knowledge and consequently were also important to evaluate. Item response theory (*IRT*) was used to perform this evaluation. This analysis provided information about each item's quality, difficulty, and its ability to discriminate between ability groups. Winsteps (Linacre, 2005a) was employed to evaluate the Rasch model describing this type of data because it can be used to analyze samples as small as 100, while both the 2-PL and 3-PL models require sample sizes in excess of 1,000 (Linacre, 1994). Our sample sizes were on the order of several hundred for each test.

The unidimensionality of items was an important quality to assess to establish the content validity of these tests. Unidimensionality means the likelihood of successfully answering an item is only reflective of a single ability. This is important to assess because multidimensionality of items would adversely impact the reliability and validity of the assessments. *IRT* can provide important information regarding the *unidimensionality* of items and therefore can provide some evidence useful to determine the reliability and validity of this assumption for a given test (Hambleton, Swaminathan, & Rogers, 1991). The indices considered important for *IRT* analysis were item difficulty, discrimination, and item misfit.

Additionally, the information functions (*IF*s) of the tests were calculated. Tests provide information about examinees' abilities in inverse proportion to the variance of their responses. If the IF is large, the item or test will estimate an examinee's ability with precision. However, the IF is dependent on examinee ability. This means that items may estimate with precision for examinees of one ability level, but not another (Baker, 2001). For these reasons, the IF was calculated and plotted for the spectrum of ability levels defined by the Rasch model using the Parscale® software package (Muraki & Bock, 2008). The DTAMS assessments are diagnostic assessments. For this reason, they need to yield information about a broad spectrum of abilities. IF curves that meet this criterion tend to be relatively flat.

Validity Results

Structural Equation Models

Analysis of the structural equation models indicated that with the exception of the probability and statistics test, all structural models adequately described the sample data (see Table 2). The low *CFI* and *TLI* values for the Probability and Statistics test indicated that there either may have been some misspecification in the model or that the teacher responses did not meet important assumptions. Examination of the Probability and Statistics test estimates and modification indices did not indicate model misspecification was a problem. Graphing the Probability and Statistics teacher response data revealed potential non-normality in the data. In particular, it revealed a negative skewness for Knowledge Types I and II items, and a positive skewness for Knowledge Types III and IV items. This means the greater part of teachers found Knowledge Types I and II items to be relatively easy while at the same time the majority found Knowledge Types III and IV items more difficult. Differential skewness can

Table 2
SEM Goodness-of-Fit Indices for Test Content and Knowledge Type Structures

Content Test	χ^2	*dF*	*CFI*	*RMSEA*	*TLI*
Probability and statistics					
Content	1,008.77*	389	.86	.065	.84
Knowledge type	1,008.3*	389	.86	.066	.84
Algebra					
Content	3,813.43*	389	.99	.047	.98
Knowledge type	3,908.18*	389	.99	.048	.98
Geometry measurement					
Content	4,869.46*	389	.95	.068	.94
Knowledge type	4,877.89*	389	.96	.062	.95
Number computation					
Content	3,460.57*	389	.97	.057	.97
Knowledge type	3,312.11*	389	.97	.056	.97

* Significant at $\alpha = .01$ level.

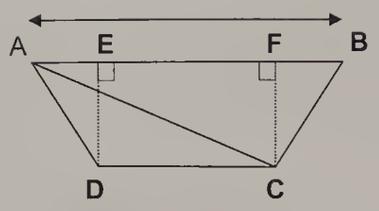

Figure 1. DTAMS geometry questions with insignificant regression weights.

result in underestimation of the structural equation model (Byrne, 1998).

With the exception of two items on the geometry assessment, the questions on all four assessments contributed significantly to their content and knowledge type structures. This result indicated that the assessments were measuring the content and knowledge type understanding intended by the designers. One geometry item did not contribute significantly to the knowledge type structure, but did provide a significant contribution to the content structure. This item was designed to provide information about two-dimensional geometry knowledge at a conceptual level (see Figure 1, item 6). The other geometry item did not contribute significantly to the content model, but did contribute to the knowledge type model. It was designed to provide information about two-dimensional geometry at a problem-solving level (see Figure 1, item 12). Examination of the two questions did not reveal any structural or semantic elements that may have caused the aberrant behavior.

Item Response Theory

Item difficulties and discrimination were calculated and graphed to measure the psychometric properties of individual items. Results were displayed using a modified box plot format designed to provide maximum information with fewest distracting elements (Tuffte, 1983). This format depicts the median with the central diamond shape. The first and third quartiles are depicted respectively with the lower and upper line segments. When outliers exist they are depicted by smaller diamonds.

Analysis of Figure 2 indicated that across all the tests, the range of item difficulties for less difficult items were greater than the corresponding range of more difficult items. In addition, the differential between the difficulties of zero-difficulty items and the easiest items was greater in magnitude than the corresponding difference between the zero-difficulty items and the most difficult (see Figure 2).

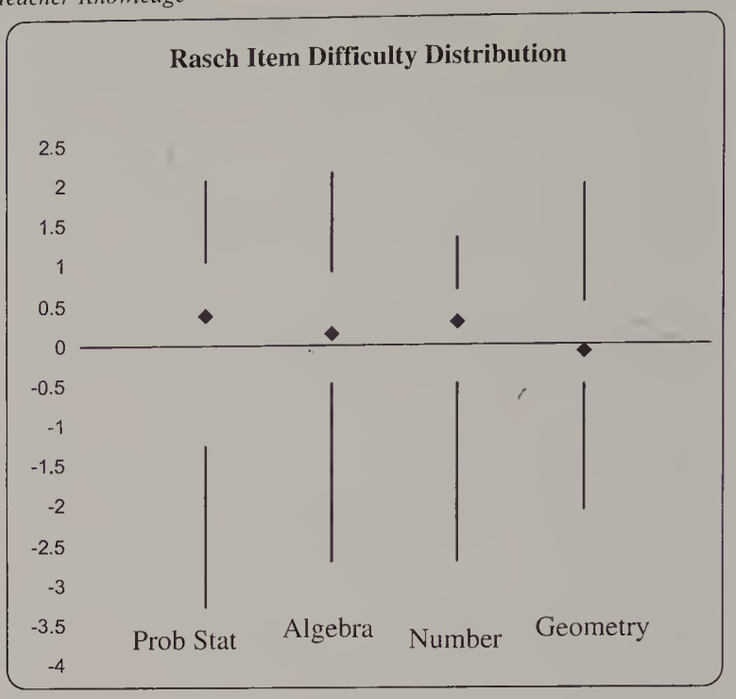

Figure 2. Rasch item difficulty distributions for four DTAMS mathematics assessments.

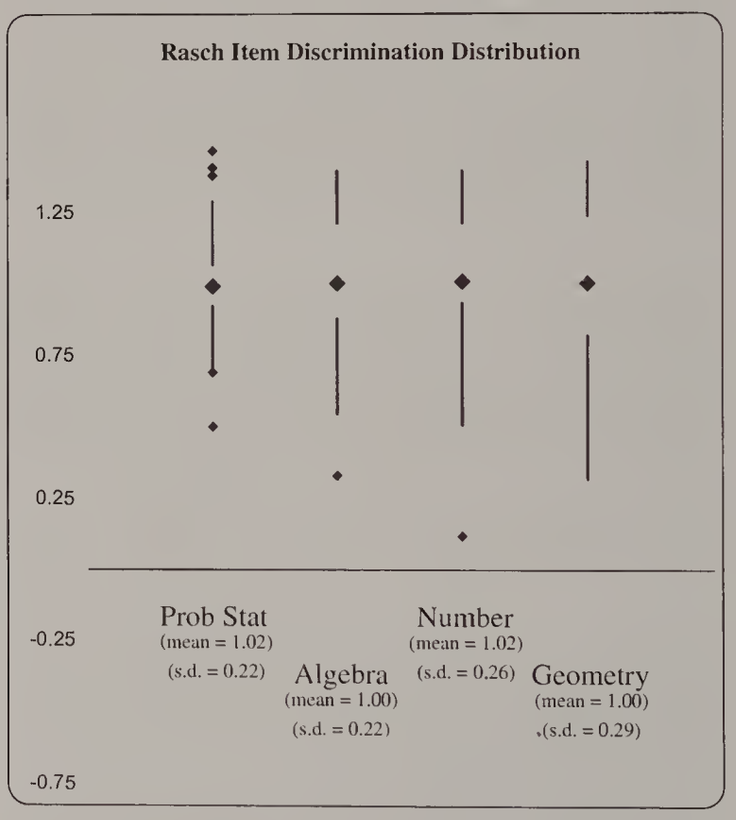

Figure 3. Rasch item discrimination distributions for four DTAMS mathematics assessments.

Figure 3 displays the Rasch item discriminations of items on the assessments. The DTAMS mathematics assessments were less discriminating than the Rasch

Table 3
DTAMS Test Total Information Function and Standard Error Values

Ability Level	Geometry		Algebra		Prob/stats		Num/comp	
	IF	*SE*	*IF*	*SE*	*IF*	*SE*	*IF*	*SE*
−3	1.30	.88	1.30	.88	1.15	.93	1.30	.88
−2	2.10	.69	2.10	.69	2.05	.70	2.80	.60
−1	3.10	.57	3.10	.57	3.10	.57	4.80	.46
0	3.65	.52	3.70	.52	3.80	.51	5.70	.42
1	3.10	.57	3.10	.57	3.20	.56	4.80	.46
2	2.10	.69	2.10	.69	2.00	.71	2.80	.60
3	1.30	.88	1.30	.88	1.00	1.00	1.30	.88

model predicts. This may be indicative of the content focus of the assessments and that they were not normative in nature.

Rasch item infit describes the extent to which items are predicted from the Rasch model. Values between 0.5 and 1.5 are considered productive for analysis (Linacre, 2005b). Across the DTAMS mathematics assessments median infit values were nearly one, and ranged between about 1.35 and 0.75 at the extremes indicating these items fit the Rasch model fairly well and analysis based upon their results would be productive.

Information Functions

IFs for all four DTAMS assessments were calculated and plotted using Parscale® software package (Muraki & Bock, 2008). Table 3 displays the IFs for each of the tests organized by ability level. Each of the four tests provide a fairly high degree of information for a large central range of ability levels ($-2 \leq \Theta \leq +2$, $I > 2$, where I = information, Θ = ability level, and the scale is in logits). The information is higher still for ability levels between −1 and +1 logits where the information is greater than 3 for all tests. For example, refer to Table 3 to see that the estimate of the *IF* at ability level 0 on the Geometry/Measurement Test is 3.65 and its standard error of the estimate is .52. This means that this 68% of the estimates of this ability level fall between −.52 and +.52.

Mathematical Knowledge Results

Teachers from 17 states completed the DTAMS assessments. Approximately 2,300 assessments representing approximately 1,600 unique individuals were included in this analysis. These teachers were predominately practicing middle-school mathematics teachers attending Math/Science Partnership workshops or enrolled in college coursework. Many of these test sites were administering the DTAMS assessments before and after the intervention to use as measures of impact. Because there was significant variation in the length and nature of the workshops and courses, only pretest data were analyzed for this study.

Across assessments and subdomain categories, there was significant variance in teacher performance, but average scores clustered uniformly around 50% (see Table 4). Analysis of variance was completed for each of the subdomain scores and for each of the knowledge type scores to determine if there were differences between them. This analysis indicated that within each content domain the subdomain means were all significantly different from each other with the exception of two geometry subdomains: measurement and transformations/coordinates.

Assessment items were written based upon judgment of teacher understanding necessary to teach students the mathematics content outlined in national standards documents. All essential content and knowledge types were equally represented on the assessments. For this reason, average teacher scores on these assessments of 50% indicated that middle-school mathematics teachers who completed the assessments knew approximately 50% of the content necessary to teach mathematics to their students. On all tests across content subcategories, only approximately 17% of teachers scored higher than about 70%.

Table 4
Mean Percent of Correct Responses of Teachers for Mathematical Content

Content Test	*N*	Subdomain		Total	
		Mean	*SD*	Mean	*SD*
Probability and statistics	563			.48†	.20
Probability		.44	.21		
Data		.52	.22		
Algebra	653			.47	.23
Patterns and functions		.47	.24		
Equations and inequalities		.47	.27		
Expressions and polynomials		.49	.26		
Number Computation	449			.52	.21
Whole numbers		.49	.23		
Rational numbers		.51	.29		
Number theory		.52	.27		
Integers		.59	.27		
Geometry	567			.54	.20
Two-dimensional		.48	.27		
Transformation and coordinates		.52	.26		
Measurement		.52	.25		
Three-dimensional		.61	.25		

† Means are expressed as percentiles.

Table 5
Mean Percent of Correct Responses for Knowledge Type on the DTAMS

Content Test	Type I		Type II		Type III		Type IV	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Probability and statistics	.63†	.19	.63	.23	.32	.25	.34	.25
Algebra	.61	.24	.55	.25	.43	.27	.30	.26
Number computation	.63	.23	.58	.25	.43	.27	.52	.21
Geometry measurement	.64	.20	.63	.21	.33	.26	.54	.29

† Means are expressed as percentiles.

Similar analysis of the knowledge type means showed that Knowledge Types I and II were clustered together and that Knowledge Types III and IV were clustered together (see Table 5). Significant differences did exist between lower-level knowledge (Types I and II) and higher-level knowledge (Types III and IV) however. Across assessments, teachers were much more successful when answering declarative and conceptual questions than problem solving (Type III) or *PCK* (Type IV) questions.

Discussion

Mathematical Knowledge

The average scores on these assessments indicate that the teachers in this sample possessed only about 50% of the middle-school content needed to guide students' acquisition of the mathematical knowledge described in national documents. Based on these results, the middle-school mathematics teachers who were assessed did not demonstrate the knowledge of the content required to teach the middle-school mathematics curriculum. To further make this task more difficult for teachers, the content they do know is at lower levels of knowledge.

Part of the purpose of this assessment is to provide this important feedback to teachers, colleges of education, and professional development providers regarding needed areas for intervention. The work of Ball and Bass (2003) suggested identifying what teachers know well and what they know less well is an important question for leveraging resources wisely toward the improvement of teachers' opportunities to learn mathematics. The results point to the magnitude of challenges facing middle-school teachers in order to address the national and state mathematical mandates in addition to meeting the diverse needs of their students.

One way to meet the mathematical needs of the preservice and practicing teachers is through professional development workshops and college courses. Professional development has been shown to be most effective when it addresses the changing needs of teachers, incorporates their input, and builds on their current knowledge (Mullens, Leighton, Laguarda, & O'Brien, 1996). Possession of information about participants' prior knowledge would enable these opportunities to more effectively enhance teacher knowledge.

The current push to "teach for understanding" requires teachers to have a deeper understanding of the mathematics. This movement is placing significant demands on teachers' content knowledge and pedagogical skills (Corcoran, 1995). The mean results for conceptual understanding Type III knowledge (see Table 5) were between 30 and 40% across all assessments. This indicates that across all content domains developing and providing high-level learning opportunities in an inquiry based, problem-solving method may be beyond the capacity of many teachers. Results of the Type IV knowledge assessment (see Table 5) representing how teachers identify and correct student misconceptions, were approximately 50% for number computation and geometry and measurement, but only about 30% for the Algebra and Probability and Statistics assessments. An inference that may be drawn from these results is that teachers were unable to recognize and adequately address student misconceptions. The results point to the need for professional development providers, mathematicians, and teacher educators to provide more on-target authentic professional development experiences based on the content and knowledge needs of their preservice and in-service teacher participants.

Quality of the Assessments

The analysis confirmed that these assessments produce reliable and valid measures of both essential mathematics content and knowledge type. The confirmatory factor analyses evaluated by the SEM indicate the conceptual framework structuring these instruments is well supported by the items. Determining if the tests could simultaneously measure content understanding and knowledge type was essential to the construct validity of the assessments. SEM provided validation of the relationship between the items and the concept and knowledge type structures for which they were written. *IRT* analysis provided validation of psychometric properties of individual items indicating that results they produced would be useful. The box plots of the difficulty and discrimination coefficients showed a good balance and well within accepted values. The IFs of these tests indicate that they are sensitive assessment across a broad spectrum of middle-school mathematics teacher abilities.

One area remains that requires further study, however. The Probability/Statistics assessment was not well represented by the structural equation model. This could be explained by the possibility that the middle-school teachers in this sample may not have the necessary depth of preparation in this domain. Only fairly recently did probability and statistics arise as a cornerstone of middle-school content described by NCTM 1989 Standards and subsequently was included in state assessments. Middle-school mathematics teachers often have limited course work in this area. For example, licensure requirements for middle-school mathematics teaching vary across states and some states require no coursework in this area. During the 1999–2000 school year, 43% of public school middle-grades students were in mathematics classes taught by a teacher who was certified but did not have a major in mathematics and an

additional 23% were in mathematics classes taught by a teacher who had neither a major in mathematics nor certification in mathematics (National Center for Education Statistics, 2004). This means that only 34% of the middle-school mathematics teacher population has training in the mathematics content required for today's middle-school classroom. This might explain why only 17% of our sample scored better than 70% on these assessments.

Implications of DTAMS Mathematics Assessments for Teacher Quality

One of the purposes of the analysis was to examine the nature of teachers' mathematical knowledge. The DTAMS constitutes a reliable, valid assessment that will inform middle-school teachers about their mathematical strengths and areas in which they can improve. The DTAMS assessments can provide content-specific information for school district and professional development providers, serve as an evaluation tool for determining the effectiveness of mathematics workshops, and provide pre- and post-assessment data for reviewing and evaluating content in mathematics courses for middle-school teacher certification. Teachers' specific content and knowledge gaps are valuable information for district/state providers of in-service workshops, publications for teachers and other venues of teacher learning.

The development of a tool that can provide a direct measurement of teachers' mathematics knowledge, rather than a proxy measure of knowledge like the number of mathematics courses they have taken, will inform research in two ways. First, the DTAMS assessment can provide reliable and valid data about teacher mathematics content knowledge as well as the level of teacher's knowledge related to student misconceptions. In turn, this information can be used by teachers and school districts to examine connections between teacher knowledge and student performance. The specificity of the mathematics content and knowledge level provided by the assessment data become real targets for improving mathematics instruction and subsequently student performance. Second, DTAMS provides a finer-grain measurement of teachers' knowledge that permits study of the impact of the level of knowledge on teachers' level of mathematics instruction. This tool can inform teacher education institutions, professional development providers, and other educational providers what mathematics learning prospective and practicing teachers require to provide the highest level of mathematics instruction.

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Changes in Teaching Efficacy During a Professional Development School-Based Science Methods Course

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This mixed methods study offers a theoretically grounded description of a field-based science methods course within a Professional Development School (PDS) model (i.e., PDS-based course). The preservice teachers' (n = 21) experiences within the PDS-based course prompted significant changes in their personal teaching efficacy, with the opportunities working with children afforded in the course attributed as a source of these beliefs. However, the preservice teachers' teaching outcome expectancy beliefs did not significantly shift. The results of this study support the extant literature in that field experiences with science methods courses can facilitate preservice teacher development in meaningful ways. This study expands upon this literature by considering a PDS context for science teacher preparation, more specifically, a science methods course purposefully integrated in elementary classrooms at a PDS where preservice teachers facilitated scientific inquiry projects with children. The findings should prompt new ways of thinking about teacher preparation, particularly related to science, that provide systematic and intentional connectivity between university programs and K–12 schools so preservice teachers can connect theory and practice.

National reform efforts in science education call for elementary teachers to engage students in authentic scientific inquiry (National Research Council [NRC], 1996). Many beginning elementary teachers have unsophisticated understandings of scientific inquiry, as well as low teaching efficacy toward this content area (Davis, Petish, & Smithey, 2006). Science teacher educators may be able to address these concerns by integrating science methods courses with field experiences in elementary schools. However, field experiences in conjunction with science methods courses that lack careful construction have had conservative effects on preservice teacher development (Ohana, 2004). The context of this study, a field-based science methods course held at a Professional Development School (PDS), allowed for systematic and intentional integration of the course in elementary classrooms.

A PDS is a form of collaborative partnership between an institution of higher education and a K–12 school with the purpose of school improvement through creation of a transformative learning community of educators (Darling-Hammond, 2005; Teitel, 2003). PDS models provide contexts for preservice teachers to connect theories and methods learned in university coursework with practices in elementary classrooms (Castle, Fox, & Souder, 2006). Clift and Brady (2005) argued that PDSs can "decrease the discrepancies between advocated practice and situated practice, thus increasing the congruence of messages between the school and university contexts" (p. 331). PDSs are often heralded as integral to reform in teacher preparation (Castle et al., 2006; Latham & Vogt, 2007; Ridley, Hurwitz, Hacket, & Miller, 2005), but little evidence has connected PDS models with teacher development in specific content areas such as science. The purpose of this mixed methods study is to explore changes in elementary preservice teachers' science teaching efficacy during a PDS-based science methods course.

Research

Teaching Science According to a Reform Perspective: Methods Courses and Field Experiences

Science teacher educators are currently searching for new ways to meet the challenges of teaching science according to the reform perspective of the National Science Education Standards (NSES). This perspective requires substantial paradigmatic shifts about teaching and learning science for many teachers, particularly because this is often not how they learned as students of science. NSES advocate for the importance of K–12 students developing conceptual understandings in science by engaging in authentic scientific inquiry, which is a natural process of asking questions, gathering and examining data to answer

these questions, and developing explanations (NRC, 1996). However, studies have shown that many beginning teachers tend to engage in conservative, teacher-centered approaches to science instruction, with these practices linked to limited knowledge and abilities related to scientific inquiry, as well as concerns about classroom management (Appleton & Kindt, 2002; Davis et al., 2006).

Some studies have examined the influence of field experiences on preservice teacher development in science, with very few focusing on field-based science methods courses, particularly in a PDS context. In Davis et al.'s (2006) large-scale review of the literature on "challenges new science teachers face" they concluded that field experiences with science methods courses contributed to the development of preservice teachers' understandings of science instruction and teaching efficacy. Moreover, field experiences in science developed in preservice teachers an awareness of the importance of anticipating students' ideas. From their synthesis, they concluded there is a "crucial importance of placing preservice teachers in classrooms before their student teaching experiences" (p. 19). Alternately, Ohana's (2004) comparative, qualitative study of elementary preservice teachers completing science methods courses with ($n = 21$) and without ($n = 24$) field experiences revealed that general field experiences did not facilitate change in preservice teachers' conceptions of science education. The researcher concluded that field experiences must be structured and purposeful to prompt teacher development in a meaningful way. Given the potential benefits of field experiences, this study demonstrates how a PDS-based course that provided systematic and deliberate integration in elementary classrooms might contribute to preservice teacher change, thus providing more information about potential contexts for the field-based nature of science teacher education.

Science Teaching Efficacy Beliefs

One way to indicate the benefits of science methods courses is by measuring teacher efficacy toward science. Teacher efficacy is grounded in Bandura's social cognitive theory, which is inclusive of self-efficacy. Self-efficacy is defined as an individual's belief in his or her ability to successfully execute a course of action in a difficult or challenging situation (Bandura, 1977). It is considered a two-dimensional construct, including self-efficacy expectation, which is an individual's belief in his or her ability to successfully perform a behavior, and outcome expectancy, which is one's belief that the performance of the behavior will have a desirable outcome. Bandura (1997) postulated that self-efficacy beliefs are developed from four primary sources of information: mastery experiences, vicarious experiences, verbal persuasions, and psychological and affective states.

Self-efficacy beliefs are considered to be situation specific and therefore the focus of significant attention in teaching contexts. Consistent with the two-dimensional aspect of self-efficacy, teacher efficacy comprises (1) personal teaching efficacy, i.e., an individual's belief in his or her skills and abilities to be an effective teacher; and (2) teaching outcome expectancy, i.e., an individual's belief that effective teaching will bring about student learning (Ashton & Webb, 1986; Riggs & Enochs, 1990). A large body of research literature indicates the importance of teachers having a strong sense of teaching efficacy, as these beliefs have been linked with student achievement, instructional strategies, willingness to embrace reform, and commitment to teaching (Bandura, 1997).

Consequently, the development of science teaching efficacy is an important goal for teacher preparation in science, particularly because teachers with weak science teaching efficacy tend to devote less instructional time to this content area (Raymey-Gassert & Shroyer, 1992). Preservice teachers who graduate with a strong sense of science teaching efficacy tend to make better progress as beginning teachers of science (Appleton & Kindt, 2002) and are more likely to use inquiry methods when teaching science (Anderson, Dragsted, Evans, & Sorensen, 2004). Science methods courses have been effective in increasing the science teaching efficacy of elementary preservice teachers (Cantrell, Young, & Moore, 2003; Palmer, 2001). Certain components of these courses have been linked to increasing science teaching efficacy, including the use of an inquiry approach (Jarrett, 1999), group investigations (Van Zee, Lay, & Roberts, 2003), and relating concepts to real-world experiences (Kelly, 2000). A few studies have linked opportunities for preservice teachers to practice teaching with positive influences on science teaching efficacy (Cannon & Scharmann, 1996; Cantrell et al., 2003). In a quantitative study by Cannon and Scharmann, they found that elementary preservice teachers ($n = 120$) participating in a science methods course who had experiences in field placement classrooms scored significantly higher on teaching efficacy measures

than those preservice teachers who had not had experiences in elementary classrooms.

Studies of teaching efficacy have been largely dominated by quantitative methods (Labone, 2004). There has been a call to move beyond this typical quantitative emphasis and to "expand and enrich conceptions of teacher efficacy" (Tschannen-Moran, Woolfolk, Hoy, & Hoy, 1998, p. 3) through qualitative means. This present study addresses the need for a broadened and thickened understanding by integrating qualitative and quantitative methods to explore changes in science teaching efficacy.

Research Questions

This mixed methods study used a "concurrent triangulation" approach (Creswell, Plano Clark, Gutmann, & Hanson, 2003, p. 224) to investigate changes in science teaching efficacy for elementary preservice teachers enrolled in a PDS-based science methods course. The course was held at an elementary PDS and involved preservice teachers working with children and inservice teachers while being supervised and supported by the university instructor. This integrated PDS-based course provided significant opportunities for linking coursework theories and methods with classroom practices. This study examined whether the field-based nature of the course, specifically in a PDS context, would prompt increased teaching efficacy and if this context might be attributed by the preservice teachers as contributing to this change. The following research question was explored: How do elementary preservice teachers' science teaching efficacy beliefs change during a PDS-based science methods course?

Method

Participants

This study involved 21 elementary preservice teachers (all female) at a large, urban university in the southeastern United States. The participants were completing a four-semester undergraduate teacher preparation program that used a cohort model. The program consisted of three semesters of coursework with concurrent two-day-per-week field placements followed by a semester of student teaching. At the time of this study, the cohort of preservice teachers was in the second semester of the program and completing three hours of science methods, three hours of mathematics methods, and six hours of literacy methods, in addition to having field placements in elementary classrooms. All courses met at an elementary school, Highlands Elementary (a pseudonym), which was in a PDS relationship with the university. The preservice teachers' field placements classrooms were mostly not at Highlands, although a small number of the preservice teachers were placed at the PDS.

The researchers were involved at the PDS and in the site-based coursework in several ways. The first author taught the PDS-based science methods course, and the second author taught the PDS-based literacy methods course. These close interactions with the preservice teachers did not hamper data collection but rather provided insights about the experiences and anecdotes referenced in the data. The researchers acknowledge, however, that some of the preservice teachers might have felt obliged to answer positively during data collection. Therefore, measures were taken, such as collecting final data upon completion of the coursework as well as using a graduate research assistant during the data collection process, to minimize bias in the data.

Context

Highlands was a large, suburban elementary school located somewhat near the university. The school had Title I status with 93% of students considered economically disadvantaged. Student demographic groups included Hispanic (65%), African American (20%), Asian (8%), multiracial (4%), and White (3%). Around three-fourths of the students were nonnative English speakers and 44% participated in the English as a Second Language program. The PDS had a high rate of student mobility coupled with problematic teacher turnover. In 2002, this school was removed from the state's failing schools list and had achieved adequate yearly progress goals in the subsequent years.

One of the researchers served as PDS university liaison at Highlands for two years prior to this study. In this capacity, she spent one day per week at the school supporting collaborative activities (e.g., preservice teacher placements, site-based coursework, professional learning communities, collaborative inquiries, and professional development) and facilitating communication and relationship building between the university and school. Most of her responsibilities were in response to the needs of the PDS, and the science education of Highlands' students was of significant concern to teachers and administrators. The most recent data from the fourth-grade state-mandated science test indicated that 42% of students did not meet the standards. Coupled with this problem, the

teachers perceived science to be a neglected subject, with greater classroom instructional emphases on the high-stakes content areas of mathematics and literacy. Additionally, teachers believed that the pronounced focus on high-stakes testing was diverting attention from the accomplishments and celebration of individual students. In order to address these concerns, the PDS university liaison developed her science methods course to be taught onsite and work directly with students and teachers at Highlands.

A major goal of the three-hour science methods course was for preservice teachers to develop an understanding of and confidence in scientific inquiry; further, preservice teachers, upon completion of the course, should be able to create inquiry-based learning environments in science. As a component of the course, the preservice teachers worked in four fourth-grade classrooms at Highlands to facilitate scientific inquiry projects. In addition to the scientific inquiry projects, the preservice teachers implemented at least two science lessons in their field placement classrooms.

The fourth-grade teachers at Highlands volunteered their classrooms in response to an invitation extended to all teachers at this grade level that outlined expectations for the processes and outcomes of the scientific inquiry projects, and more importantly, highlighted the benefits to children. Because the instructor of the science methods course was also the PDS university liaison to Highlands, many of the teachers were familiar with her, and this rapport allowed the teachers to feel comfortable in volunteering. The instructor considered it important that this experience be transformative not only for the preservice teachers but also for the fourth-grade teachers as they observed effective teaching of science through inquiry. Additionally, throughout the experience, the instructor communicated with the fourth-grade teachers. She met with them frequently, including before, during, and after the project implementation, to provide a full explanation of the scientific inquiry projects as well as address any questions and concerns. Further, she wanted them to understand that this experience was a negotiable and flexible process and that their suggestions and expertise were welcome.

In order to facilitate the scientific inquiry projects, the preservice teachers worked in partnerships with small groups of fourth-grade children across four days (four days in two classrooms, then four days in two other classrooms, so a total of eight days for all four classrooms). On day one, the children generated science-related research questions and planned an investigation for answering these questions. The preservice teachers prompted their questions through scientific demonstrations, informational literature, and discrepant events. On days 2 and 3, the children conducted their investigations and generated conclusions while the preservice teachers facilitated these processes. On day 4, the children, in conjunction with the preservice teachers, created a project board communicating their scientific inquiry projects. This four-day process culminated in a science fair where the boards were displayed and the children explained their projects to other students at Highlands who visited the fair while the preservice teachers supervised. After each day, the instructor of the course and preservice teachers had a debriefing time that involved reflection on the preservice teachers' work with the children. The discussion focused on children's learning and misunderstandings as well as teaching successes and concerns.

To accommodate the projects, the typical course schedule was modified, resulting in the course largely being held in the first two months of the semester. One week was allowed between day 1 and day 2 to provide the preservice teachers time to procure materials and informational literature to address the children's research questions. Because the research questions were child generated and thus distinct, the preservice teachers needed to buy specific materials for the investigations. The preservice teachers were provided financial assistance from the elementary education department to purchase these materials. Days 2, 3, and 4 occurred within one week to allow for a seamless learning experience for the children during the inquiry projects.

Data Sources

This mixed methods study used a "concurrent triangulation" design (Creswell et al., 2003, p. 224). Data were collected through surveys and open-ended questionnaires. The concurrent triangulation design included quantitative and qualitative data collected concurrently, given equal priority, and integrated in the interpretation phase.

During the first and last class session, the preservice teachers completed the Science Teaching Efficacy Belief Instrument (STEBI) Form B (Riggs & Enochs, 1990). The STEBI (Form B) is a 23-item survey measuring the science teaching efficacy beliefs of elementary preservice teachers. It has two subscales

consistent with the two-dimensional aspect of teaching efficacy: 13 items on the personal science teaching efficacy (PSTE) subscale and 10 items on the science teaching outcome expectancy (STOE) subscale. The PSTE subscale assesses elementary preservice teachers' beliefs in their skills and abilities to be effective teachers of science, and the STOE subscale measures elementary preservice teachers' beliefs that effective teaching of science can influence student learning. The instrument uses a Likert-type scale with five response categories, with higher scores indicating greater science teaching efficacy. Possible scores on the PSTE subscale range from 13 to 65; STOE subscale scores range from 10 to 50. The subscales have established reliability (Chronbach's alpha = .90 for PSTE and .76 for STOE) and represent independent constructs based on confirmatory factor analysis.

During the first class session, the preservice teachers also completed a questionnaire requesting demographic information as well as a response to two open-ended questions focusing on PSTE: What do you believe about your ability to teach science? Why do you believe this? After the conclusion of the science methods course, the preservice teachers completed an open-ended questionnaire containing these same questions.

Data Analysis

To examine changes in science teaching efficacy as measured by the STEBI, Wilks' Lambda and its associated *F*-statistic were used in analyzing the initial and final data on the two subscales, PSTE and STOE. Consistent with a mixed methods concurrent triangulation design, data from the initial and final open-ended questionnaires were analyzed to provide insights into the quantitative findings for convergence in the interpretation stage. Constant comparative methods were used in analyzing the qualitative data (Lincoln & Guba, 1985).

The qualitative data related to PSTE were initially considered by sorting the initial and the final open-ended questionnaires into three groups based on the responses of the preservice teachers to the question "What do you believe about your ability to teach science?" The initial and final answers were grouped according to those who largely (1) responded affirmatively in their PSTE; (2) responded negatively in these beliefs; or (3) responded with uncertainty in these beliefs. The third category included those preservice teachers who expressed negativity or doubt regarding their PSTE but yet perceived this disbelief could be overcome through various means (i.e., science methods course, teaching resources, etc.). The three groups of final and initial open-ended questionnaires were then analyzed by considering the follow-up question "Why do you believe this?" related to their PSTE. With the individual as the unit of analysis, the initial and final data were compared across cases in the three groups to allow for data reduction and refining of the emergent findings.

Results

Quantitative Findings

Mean scores and standard deviations from the administrations of the STEBI subscales are provided in Table 1. Table 2 indicates the statistical significance of the differences between the initial and final mean scores of the preservice teachers using Wilks' Lambda and its associated *F*-statistic.

The preservice teachers had significant increases in their PSTE subscale mean scores, as indicated in Table 2. The preservice teachers' beliefs in their skills and abilities to teach science effectively became significantly stronger during the PDS-based science methods courses. When considering mean changes (see Table 1), the preservice teachers had a 10-point increase from the beginning of the methods course to

Table 1
Means and SDs for Preservice Teachers' Science Teaching Efficacy Scores

Subscales	Means		*SD*s	
	Initial	Final	Initial	Final
PSTE	39.33	49.90	6.45	6.08
STOE	36.24	36.95	4.01	4.32

Note. Possible scores on the PSTE subscale range from 13 to 65; STOE subscale scores range from 10 to 50.

Table 2
F Values and p Values for Preservice Teachers' Science Teaching Efficacy Scores

Subscales	F value	*p* value
PSTE	79.13	.000
STOE	1.05	.319

Note. $df = 1, 20$.

the end of the course on this subscale. However, the preservice teachers did not have significant changes in their STOE subscale mean scores, as shown in Table 2. These beliefs of the preservice teachers remained essentially unchanged (see Table 1) during the PDS-based science methods course; thus, their beliefs that effective teaching of science can influence student learning did not shift.

Qualitative Findings

When considering the significant changes in PSTE, analysis of the initial and final open-ended questionnaires revealed some commonalities between groups (e.g., negative, uncertain, and positive) of individuals. This analysis involved a review as to why the preservice teachers believed what they believed at the onset and completion of the course. Initially, or at the beginning of the course, four preservice teachers had negative PSTE, eight had uncertain beliefs, and nine had positive beliefs. Those preservice teachers who initially expressed negativity or uncertainty about their PSTE had three salient reasons: (1) negative past experiences with science (sometimes cited in the context of a learner of science); (2) lack of adequate science content knowledge; and (3) a dislike toward science as a subject. Illustrative statements from the preservice teachers include "Unfortunately, science was one of my least favorite subjects in school partly because of some of the teachers I had and partly because it never interested me"; "I think I need to refresh my memory because I am nervous about a student asking me a question that I cannot answer"; "I don't feel I know as much as I should about the subject [science]"; and "I have never liked the subject [science]." Conversely, those who expressed a strong sense of efficacy toward teaching science at the beginning of the science methods course cited (1) strong content knowledge (e.g., "I feel I have a strong background in science"); (2) positive past experiences with science (e.g., "I have so many experiences and things to draw from [when teaching science]. My mother owned a pet store for seventeen years"); (3) enjoyment of science as a subject (e.g., "Growing up I always loved science"); and (4) enthusiasm for the perceived pedagogical strategies (e.g., "hands-on," "interactive," etc.) involved in teaching science (e.g., "Science can be taught very creatively, and I'm very excited").

When considering the final data from the open-ended questionnaires, the preservice teachers' answers to questions on PSTE indicated 5 with uncertainty toward these beliefs while 16 asserted positive personal teaching efficacy. Perhaps most notably, at the end of the course none of the preservice teachers expressed largely negative PSTE. In examining the open-ended questionnaires, the preservice teachers with uncertainty linked their doubts with two reasons: inadequate content knowledge (e.g., "I am not sure about my content knowledge . . . I still fear that there will be many questions asked by the students that I will have a difficult time answering") and lack of experiences teaching science, particularly from a reform perspective (e.g., "I am sure with more practice [teaching science] I will feel differently. I feel I must come up with spectacular lessons to teach it").

Preservice teachers who expressed positive PSTE at the end of the science methods course attributed these beliefs to three salient rationales. First and foremost, they cited opportunities to teach from a reform perspective (e.g., "inquiry," "interactive," "hands-on," "exploration") embedded in the course and an enjoyment of such as contributing to their sense of efficaciousness. These viewpoints are expressed in the following statements: "I realize how important inquiry is when teaching science. All the science lessons I performed with my students were all enjoyed by them, and when they enjoyed them, I enjoyed them" and "In performing my science lessons this year in such a hands-on, inquiry-based way, I have been more successful and learned a lot, which has made me many times more confident in my science abilities." Coupled with these perspectives is the second rationale, which is the student-centeredness of teaching science, realized through their teaching experiences with children. The preservice teachers particularly noted from their work with children a child's "motivation," "interest," "curiosity," and "thinking" in science. Example preservice teacher statements include "I've discovered that I'm always eager to watch and help spark a child's curiosity for something" and "I enjoy teaching science and look forward to watching the students conduct their experiments and hear their answers to why things are happening." Third, the preservice teachers linked their efficaciousness toward teaching science to their increased knowledge of teaching strategies and resources in science. For example, a preservice teacher stated, "I also have many [teaching] ideas, and I know what my resources are if I need more ideas."

Discussion and Conclusions

The results of this study support the extant literature in that field experiences with science methods courses

can facilitate preservice teacher development in a meaningful way. This study expands upon this literature by considering a PDS context for science teacher preparation, more specifically, a science methods course purposefully integrated in elementary classrooms at a PDS where preservice teachers facilitated scientific inquiry projects with children. The findings should prompt new ways of thinking about teacher preparation, particularly related to science, that provide systematic and intentional connectivity between university programs and K–12 schools so preservice teachers connect theory and practice. Such a model provided a context for the preservice teachers in this study to have significant changes in their personal teaching efficacy, with their experiences working with children in the PDS-based course attributed as a source of these beliefs. In time, if their personal teaching efficacy is maintained, these preservice teachers may be more likely to include inquiry in their science instruction (Howes, Lim, & Campos, 2008).

Science methods courses have not historically been researched as field-based courses, particularly in PDS settings. Clift and Brady (2005) found only 21 studies published between 1995 and 2001 that document field experiences in conjunction with science methods courses (8 of which were conducted by one researcher). Our study offers a theoretically grounded description of a field-based science methods course within a PDS model. The preservice teachers' experiences within this setting prompted significant changes in their personal teaching efficacy. Bandura (1977) postulated that the most influential source for efficacy beliefs of individuals is mastery experiences, where successes build efficacy beliefs and failures undermine them. The insights provided by the qualitative data reveal that preservice teachers attributed their personal teaching efficacy at the end of the course to their mastery experiences teaching reform-oriented science embedded in the PDS-based course and the sense of affirmation in doing such. However, those who were uncertain about their abilities in teaching science at the end of the course linked these beliefs with a lack of experience in teaching science from a reform perspective, suggesting the need for even more mastery experiences in teaching this content area.

The teaching experiences integrated in the PDS-based course may be particularly important given the conclusion from Davis et al.'s (2006) review of the research literature that science instruction was often pushed from the schedules of many elementary classrooms because of the current high-stakes testing era. Specifically, the researchers pointed out that "elementary teachers found that science was not emphasized in their schools . . . science had a low priority" (p. 13). The effects of high-stakes testing on science, either because it pushes science from the foreground or because it causes an overemphasis on recalled facts, are concerning to scientists and science teachers alike (Taylor et al., 2008). In considering this finding, the preservice teachers in this study may have had limited opportunities to teach and observe science, particularly through inquiry, in their field placement classrooms. Given the positive link between personal teaching efficacy and teaching experiences embedded in the PDS-based course, perhaps a purposeful field-based component is *particularly* important for science methods courses.

The preservice teachers also perceived that the student centeredness involved in teaching science positively influenced their personal teaching efficacy. The preservice teachers noted children's "motivation," "interest," and "thinking" in science, which prompted the preservice teachers to be more confident teachers of science. An emphasis on children's thinking during teacher preparation is considered to be an effective mechanism for teacher change (Sowder, 2007). This kind of focus is not always advocated or afforded in traditional methods courses that often promote an academic understanding of theoretical perspectives or a series of methods. By guiding a young child through a sequenced, structured inquiry project, the preservice teachers in this study had to attend to the child's questions, insights, and learning. They had to develop lessons, demonstrations, and exploratory inquiries guided by authentic questions generated by children. Davis et al. (2006) noted that this kind of understanding—the understanding of learners and knowledge about the process of scientific inquiry—is uncommon in science teacher education. They suggest that "early teaching experiences" (p. 8) (such as field-based coursework) can help preservice teachers develop this understanding. In this study, the preservice teachers linked their personal teaching efficacy at the end of the course with the child centeredness afforded in the PDS-based course.

Upon completion of the PDS-based course, the preservice teachers who expressed uncertainty toward personal teaching efficacy linked these beliefs with perceived inadequate content knowledge. The

development of science content knowledge is of pressing concern, but this knowledge largely should have been learned in science content courses completed before entering the teacher preparation program, prior to taking the sole science methods course required for teacher preparation. Additional coursework devoted to building the science content knowledge needed for teaching elementary science might better serve these preservice teachers. Further, the preservice teachers' concerns about their own lack of content knowledge may have been exacerbated by the imminent state teacher certification test, which assesses in science only broad content knowledge rather than pedagogy. Initially, 12 preservice teachers expressed largely negative or uncertain personal teaching efficacy on the open-ended questionnaire, and they linked these beliefs to perceived inadequate content knowledge as well as negative past experiences with science and a dislike of science. It is noteworthy that only five preservice teachers asserted uncertain personal teaching efficacy at the end of the course, with none expressing largely negative beliefs. This positive finding suggests that some of the salient challenges for science teacher preparation can be influenced by experiences in science methods courses in PDS or field settings that provide experiences working with children. While advocating for additional science content coursework, we also recognize that the PDS-based course aided in the preservice teachers' perceptions of their own content knowledge. Further studies might investigate innovative programs or coursework that could mediate both content and pedagogical content knowledge to further improve science teaching.

In considering the two-dimensional aspect of teaching efficacy, the lack of change in the preservice teachers' teaching outcome expectancy is not surprising given the preservice teachers' extensive work with children embedded in the PDS-based course. Longitudinal studies of preservice teachers' teaching outcome expectancy reveal that these beliefs increase during college coursework and then decline during student teaching (Hoy & Woolfolk, 1990; Plourde, 2002). This decline has been attributed to the unrealistic optimism preservice teachers often have prior to student teaching about teachers' abilities to overcome negative influences. Perhaps the preservice teachers' immersion experiences in elementary classrooms in this study contributed to the stabilization of their teaching outcome expectancy and provided a better understanding of the myriad and complex factors influencing student learning.

Also of note, and perhaps worth celebrating most heartily, is that this PDS-based science methods course resulted in the first-ever science fair at Highlands. This integrated course addressed the needs and concerns of the stakeholders at Highlands (see "Context" section). Informal feedback from elementary students, teachers, and administrators was overwhelmingly positive. As the Highland teachers had requested, individual children's accomplishments were highlighted and celebrated during the science fair. Not only was this a valuable learning experience for the preservice teachers and children, the inservice teachers were afforded numerous opportunities to observe and support effective science teaching through inquiry processes as the preservice teachers worked with their children. Studies of practicing teachers have shown this kind of observation and peripheral participation is necessary for teachers as they learn how to integrate inquiry into their daily curriculum (Cuevas, Lee, Hart, & Deaktor, 2005; Howes et al., 2008). Future research on PDS models might examine how courses like this, in which there are "generations of learners" (an invented term referring to the child, preservice teacher, inservice teacher, and course instructor as a group), can be mutually beneficial and how each member of the generations contributes to and constructs understandings.

PDS models have been criticized for the tremendous fiscal and personnel demands placed upon universities but yet are often heralded as integral to reform in teacher preparation and K–12 schools (Levine, 2006). More research needs to show the value-added evidence of PDS models in teacher preparation, particularly related to specific content areas such as science. Further, additional study should explore a more nuanced view of teaching efficacy to provide a better understanding of this construct as it relates to teacher development. For example, teaching outcome expectancy could be investigated in an in-depth way using qualitative methods. As with any study, this one has limitations. The research was carried out over one semester, focused on only one course, and included a small number of participants. Future research might investigate a PDS-based program over a longer period of time within multiple school settings that involves a greater number of participants. Finally, there are contextual nuances that contributed to the success of this study that need to be accounted. First, because of the

unwavering support of the university department in this study, the preservice teachers were provided with monetary support to facilitate their work with children and, while this was not a focus of our research, the preservice teachers were very appreciative of this help. Although this can hardly be considered a limitation, this kind of financial support is not always the case. Second, the methods course took place after years of developing a PDS relationship between the elementary school and the university. The relationship provided many benefits, both tangible and intangible, such as classroom space for the preservice teachers to meet, open and honest conversations about what inservice teachers wanted from the methods course, and a willingness by school personnel to engage in the collaborative course. These contextual factors are essential to understanding how the PDS-based science methods course achieved success.

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A Partnership Approach to Improving Student Attitudes About Sharks and Scientists

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*This article describes the methods and impact of a student–teacher–scientist research partnership on student attitudes. The partnership objective was to teach students about the diverse roles of sharks in the marine environment while personally connecting students with scientific study. Students (N = 229) participated in lessons about shark biology and helped the partnering scientist design experimental protocols and analyze data. A self-selected subset of students also volunteered (n = 82) for a field component working with live hammerhead sharks (*Sphyrna lewinii*). Student surveys before and after the partnership suggested that negative attitudes about sharks are due largely to lack of exposure, and direct attention to students' stereotypes about sharks resulted in significant attitude improvement. Change in students' attitudes toward scientists, however, was minimal. Students' negative views of scientists did decline significantly, but their overall views of scientists were relatively positive to begin with. Also of interest was the students' unremitting association of scientists with specialized equipment and the students' lack of personal connection to scientific ways of examining the world, suggesting that partnerships may be more effective at personally connecting students with scientific process if they explicitly incorporate activities designed to improve students' view of themselves as scientists.*

According to social cognitive theory, behavior is reflective of a person's attitudes, beliefs, and knowledge within a social context (Bandura, 1986; Zimmerman, 1983). Actions are a result of how beliefs interact with culture and society. In an educational context, social cognitive theory impacts students' motivation to study on a daily basis and motivation to pursue particular careers over the long term (Hammrich, 1997). Moreover, because student attitudes and perceptions are an integral component of their motivation to learn (Palmer, 2005), improving attitudes is critical for successful science education.

When prior knowledge is rooted in societal convention and in emotions, it can be very difficult to change attitudes. This is especially true with topics, like sharks, that elicit stress and fear. Successful intervention mechanisms for changing students' attitudes about such topics generally require longer time periods and experiential learning where students actively investigate their fundamental beliefs and construct new knowledge (Palmer, 2005; Phillips, 1995). Because of this, the educational utility of guest lectures or short field trips to view captive animal displays (such as aquaria and zoos) has been questioned by educators and by research scientists (Falk & Adelman, 2003; Tal & Morag, 2007). The tightening of captive animal regulations, especially with regard to elasmobranch species (i.e., sharks, skates, and rays), has further prompted science experts to question the value of captive animals for education (American Elasmobranch Society, 2004). And yet, short exposure to animals in captive environments is often the only opportunity students have to interact with these animals, which begs the question of (1) how to make short interactions meaningful and (2) how to rapidly evaluate the success of such interactions.

The Importance of Improving Students' Attitudes About Sharks

Changing students' attitudes about sharks is an important ecological concern. Sharks are a significant component of the aquatic ecosystem, yet they are being overfished at an alarming rate (Baum & Myers, 2004; Baum et al., 2003). Moreover, because public opinion of sharks is largely negative, there is a lack of concern regarding this ecological decimation of shark populations. Sharks are generally viewed as both dangerous to humans and as fishing competitors with humans (i.e., if there are fewer sharks eating fish, there will be more fish for humans to catch).

However, shark attack data and fishery models have shown that both of these concerns (fear and competition) are exaggerated. Given the numbers of people engaged in water activities worldwide, shark attacks are relatively rare. In most parts of the world, the probability of being attacked by a shark is statistically lower than the probability of being killed by a bee sting, killed by a car, or struck by lightning (International Shark Attack Files, 2008). In Hawaii, where this project was conducted, the probability of being

attacked by a shark is less than one in a million, which is also less than the probability of being injured by a falling coconut (Hawaii Department of Land and Natural Resources, 2008).

On the other hand, the real and significant risk posed by sharks is the little-recognized fact that overfishing of sharks will result in an ecosystem-wide disruption. Ecological models have repeatedly demonstrated the importance of elasmobranchs in the ecosystem (see Schindler, Essington, Kitchell, Boggs, & Hilborn, 2002). For example, the depletion of sharks has recently been demonstrated to have cascading effects down the food chain, from top-level predators to shellfish (Myers, Baum, Shepherd, Powers, & Peterson, 2007). In Hawaii, models show that the depletion of the tiger shark (*Galeocerdo cuvier*) population ultimately causes declines in tuna fish populations because tiger sharks are an important predator of juvenile seabirds, which in turn feed upon small tuna (Polovina, 1984). These examples demonstrate the integral role sharks play in the marine environment and show that decreasing shark populations will have undesired, and often unanticipated, effects. However, understanding and appreciating the role of these predators is obscured by the public's fears and myths about sharks, thereby posing a real challenge to enacting policies that will protect sharks and the overall ecosystem.

The Importance of Improving Students' Attitudes About Scientists

Part of the impetus for student–teacher–scientist partnerships is to increase student awareness about the nature of science and the process of scientific research so that students view science as accessible and connected to their daily lives. The need for this attitude shift in students is evidenced by researchers' surveys of students' attitudes. In the first documented study of high school students' attitudes about scientists, Mead and Metraux (1957) found that students believed scientists to be lab coat-wearing old men of either tall-and-thin or small stature who work in a laboratory and are surrounded by glassware. As demonstrated by Chambers' (1983) study of 4,807 students and Thomas and Hairston's (2003) study of 757 students, students' current image of a scientist still includes a lab coat, eyeglasses, and facial hair (indicating mature male). Popular media has also brought a unique set of issues to bear on students' opinion of scientists; television shows such as "CSI: Crime Scene Investigation" may help to dispel the stereotype of scientists as uncool and nerdy. But rather than making science accessible and personally relevant, the constant use of fancy equipment and stylishly dressed researchers perpetuates the misconception that science exists outside the realm of everyday experiences (Deutsch, 2006; Duncan & Daly-Engel, 2006; Willing, 2005).

Using a Partnership Approach

The purpose of this study was to investigate the utility of a student–teacher–scientist partnership model to alter students' attitudes and beliefs about sharks and to improve students' attitudes about scientists and doing science. It was hypothesized that although the intervention time was limited, the partnership approach would help students to improve their attitudes and dispel some of their stereotypic views about sharks and scientists by providing students the opportunity to (1) interact with a shark scientist; (2) learn more about sharks; and (3) participate as scientists in a shark research study.

A partnership model (Handler & Duncan, 2006) was used to couple scientific research goals with classroom work, guest teaching, and captive animal interaction. The partnership itself was a relatively short-term interaction comprising six class periods (one 90-minute class period per week for six weeks) combined with an optional field component. The goal was to maintain research integrity of the scientist's shark study while at the same time involving multiple teachers and a large number of students in the partnership. Six weeks was chosen as the duration for each student–teacher–scientist partnership because it was the amount of time needed to execute one shark research trial.

Methods

Science Education Partnership

This study was conducted as part of the National Science Foundation's Graduate Teaching Fellows in kindergarten–12th grade (GK–12) grant to the University of Hawaii at Mānoa's (UHM) Ecology, Evolution and Conservation Biology program. The grant provides fellowship support to enable science graduate students to partner with K–12 teachers and students in order to foster better communication, scientific teaching, and learning skills among all parties. At the UHM, GK–12 graduate students take part in courses to learn current science teaching pedagogy and then use their research as a basis for a partnership with

a K–12 teacher. This partnership model enables authentic interaction, mutual mentoring, and collaboration (Baumgartner, Duncan, & Handler, 2006). And although the content of lessons in this study did not explicitly address attitudes toward scientists, the overall GK–12 partnership design is intended to effect shifts in students' attitudes about scientists.

In this study, the student–teacher–scientist partnership was based on the author's graduate research on the ability of scalloped hammerhead sharks (*Sphyrna lewini*) to convert food calories into body mass. Feeding experiments were used to estimate daily caloric requirements and conversion efficiency (Duncan, 2006). The maximum number of sharks that could be kept at a time was constrained to six because of space limitations, which necessitated consecutive feeding studies to obtain an adequate amount of data. The research protocol also required the sharks to be fed every day. This design allowed the completion of a full experimental sequence with sequential groups of students every two months. In true partnership fashion, the students' help genuinely contributed to the food conversion research study because multiple people were required for the feeding and weighing procedures.

The student–teacher–scientist partnership consisted of a GK–12 graduate student researcher (the author) who partnered with four teachers, and 229 students (from 15 different high school classes at four schools). The schools and teachers were selected based on responses to an advertisement placed in the Hawaii Science Teachers Association electronic bulletin. The primary qualification was that teachers be able to devote at least one classroom lesson per week for six weeks to the shark program. During the school year, the student component of the partnership comprised students from three public high schools (four 10th–2th-grade biology classes at one school, six 9th–12th-grade marine science classes at the second school, and four 9th–10th-grade general biology classes at the third school. During the summer, the student component of the partnership comprised one 10th–11th-grade class at a summer program. A subset of students (volunteers) from each of the school year classes and all of the summer program students also participated in the optional, after-school portion of the project, helping to conduct the experiment on live sharks.

Each of the schools represented different geographic areas on the island of Oahu, Hawaii. The first school is located in windward Oahu and serves rural and urban students (student body: N = 1,796, 28.2% free and reduced lunch). The second school is located in central Oahu and serves a spectrum of military and local students from a wide range of socioeconomic backgrounds (student body: N = 2,420, 12.0% free and reduced lunch). The third school is located in downtown Honolulu and serves a high percentage (22.8%) of families living in poverty (student body: N = 2,579, 59.2% free and reduced lunch; Hawaii Department of Education, 2008). The summer program is based at the Leeward Community College in central Oahu. It helps to prepare academically disadvantaged and low-income students for high school graduation and college (Leeward Community College Upward Bound Programs, 2008).

Learning Objectives

Lessons were taught to students during their normal classroom time periods (90 minutes) by the partnering scientist and/or by the classroom teacher. In most cases, the scientist would teach the lesson, talk about it with the teacher, and make modifications and then the teacher would teach the lesson to the next group of students while the scientist helped. The order of lessons and classes was rotated to (1) familiarize teachers with lesson content (for future use); (2) allow for interaction of the scientist with each class; and (3) promote feedback from the teachers to improve the scientist's teaching style and lesson content.

The primary objective was to improve students' attitudes about sharks, and lessons were designed to highlight common stereotypes that lead to negative opinions about sharks. For example, most people tend to view sharks as stereotypically big and grey with hefty fins and large teeth for eating sizeable animals. In reality, there are more than 400 species of sharks and more than 500 species of rays, and they exist in a wide range of shapes, sizes, and habitats. Some sharks are small and colorful (like the spotted wobbegong, *Orectolobus maculates*), whereas others are large but filter-feed on microscopic plankton (like the basking shark, *Cetorhinus maximus*). The first learning objective was to combat students' misconception about the stereotypical shark and help them to recognize the diversity and variety of shark and ray forms. The additional learning objectives were for students to identify the common elements of sharks and rays and to appreciate the vulnerability of individual sharks and shark populations.

The units of instruction were structured into four main lessons that were taught in the classroom (see

Appendix), including (1) *shark biology* where students learned about the anatomy and physiology of elasmobranchs; (2) *trophic levels and energy transfer* where students learned about the transfer of energy in the food web and the interconnectedness of the marine ecosystem; (3) *diversity of shark form and function* where students learned about the variety of sharks and how they are adapted to many different environments; and (4) *combining information about sharks from cultural legends and researcher data* where students looked at traditional knowledge, legends, and media portrayals and compared these pieces of information with what research studies have demonstrated about sharks.

Elements of scientific process and experimental design were also incorporated into the lesson sequence. Using a project-based approach, students worked through the process of designing a food conversion efficiency study. The students then graphed data collected from the real experiment being conducted by the scientist in cooperation with classmates who were participating in the optional, after-school field part of the study (see below). One of the points of emphasis during the lessons was that the students' participation in the study was part of a larger project; they knew about the other participating schools, and they often graphed more than one set of data to compare results between experimental trials.

Students who volunteered for the after-school field component at the Hawaii Institute of Marine Biology (HIMB) were selected on a first-come, first-served basis. They signed up for one day per week (e.g., Monday) and agreed to come to the HIMB for three hours every Monday for four weeks. Up to 12 students from each class were allowed to participate on a given afternoon, and 82 students (out of 229 total students in all classes) participated in the field component at the HIMB. During the field component, students helped feed and maintain the captive sharks. Students also collected data on individual sharks' food consumption, health, activity rate (tail beats per minute), and growth as well as data on water conditions (temperature and dissolved oxygen). Students volunteering for the field portion were either transported on a school-provided bus or provided their own transportation.

The volunteer, field portion of the partnership allowed the students and the teachers (each teacher visited the HIMB during the field portion at least one time) to observe living sharks in a captive environment and to be part of the research study. Juvenile sharks used in the research experiments were captured prior to student involvement. The sharks were then held in controlled, captive tanks to acclimate them and prepare them for the feeding trials. During feeding trials, the student volunteers were responsible for feeding the sharks specific daily rations (from 1.5% of their body weight to all they could eat). During the experiment, students measured sharks' weight change, daily intake, and activity rates. The field component provided an opportunity for hands-on experience with experimental procedures and data collection. It was also an opportunity for students to observe the fragile nature of a living hammerhead shark, which, like most sharks, is very fragile and easily harmed by human contact or environmental disturbance.

Attitude Assessment

In order to assess students' attitudes about sharks and scientists, students were given pre and post surveys asking them to "list the first five words that came to your mind when you think of the word *shark* and the word *scientist*." Lists of words were used as a tool to gauge students' ideas about sharks and scientists. This method was used as a proxy for other well-established assessment methods, such as the draw-a-scientist test (Mead & Metraux, 1957) where students' conceptions and attitudes are evaluated through drawings. Although the draw-a-scientist test has a long history and is a reliable metric (see; Finson, 2002; Fort & Varney, 1989; Mason, Kahle, & Gardner, 1991 among others), there is not a standardized protocol for evaluating shark drawings. In addition, drawing tests can be time consuming and can overemphasize stereotypes because of the limitations of what people tend to draw, especially in the case of sharks, which are difficult to draw accurately, even for experts in the field. Therefore, words were considered a more effective vehicle for illuminating students' impressions. The use of first-impression words allowed students to write things they could not draw, and they could complete the survey relatively rapidly, which was an important concern in our time-limited interaction. Additional support for the use of words as a measure of attitudes comes from a recent study of patrons' experiences at zoos and aquariums in which patrons' first-impression words in response to the phrase "Zoo—conservation" or "Aquarium—conservation" were used as part of an analysis of attitudes on conservation in zoos and aquariums (Falk et al., 2007). First-impression words were similarly

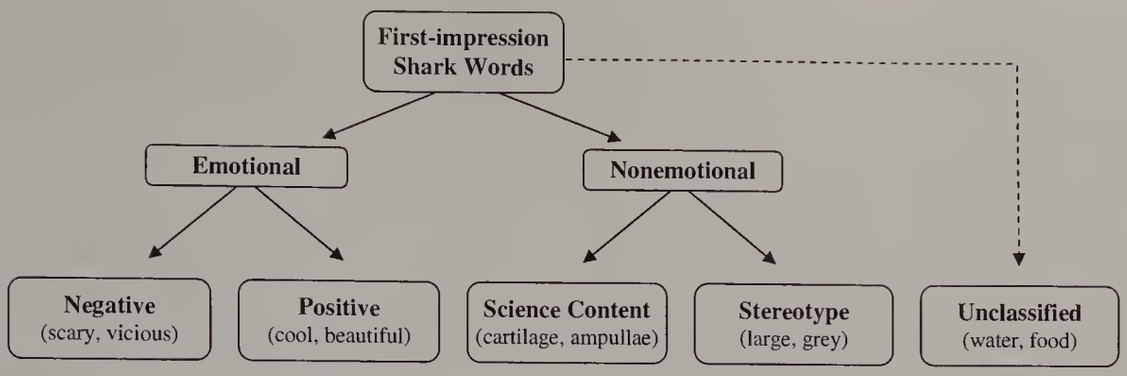

Figure 1. Flowchart used for separating shark words reported in student surveys into themes. Words were first separated by emotional versus nonemotional descriptors. Emotional words were then separated into negative and positive. Nonemotional words were separated into science content and stereotype. Words not clearly assignable were considered unclassified. Examples of commonly used words in each category are shown in parentheses.

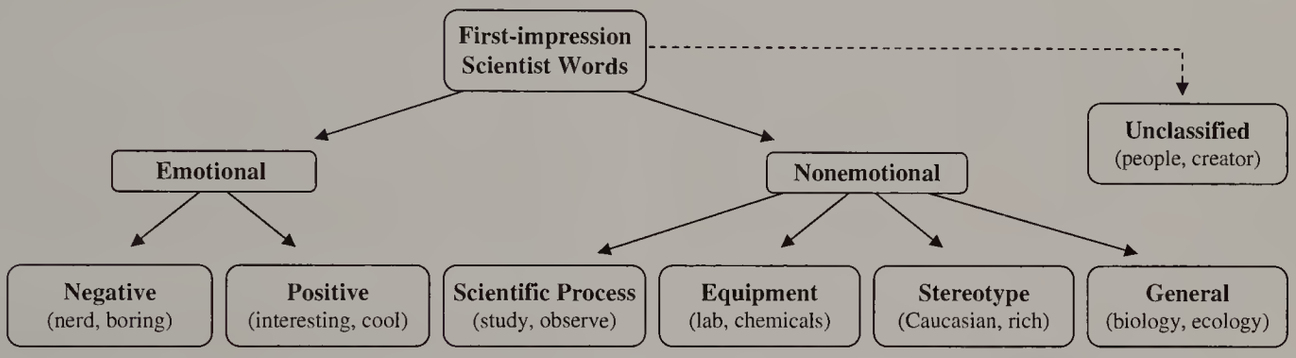

Figure 2. Flowchart used for separating scientist words reported in student surveys into themes. Words were first separated by emotional versus nonemotional descriptors. Emotional words were then separated into negative and positive. Nonemotional words were separated into scientific process, equipment, stereotype, and general. Words not clearly assignable were considered unclassified. Examples of commonly used words in each category are shown in parentheses.

used in a study of students' beliefs about the process of natural selection in evolution (Baumgartner & Duncan, 2009).

The words listed by students in this study were tallied in a database, and a content analysis was conducted to develop themes reflective of the words. The division of words into themes was independently reviewed by four researchers, who then convened to discuss and resolve differences. This process was systematic so that no one researcher had more input than others, and there was plenty of opportunity for revision to ensure that word groups were as accurate and impartial as possible. After establishing themes, a flowchart was constructed to facilitate the sorting of words (see Figures 1 and 2).

According to the flowchart generated using the themes, words associated with sharks were first separated by emotional (e.g., scary and cool) versus nonemotional (e.g., cartilage and large) categories. Within the emotional category, words were further segregated into negative (e.g., scary) and positive (e.g., cool). Within the nonemotional category, words were further segregated into scientific content target words (e.g., cartilage) that represented accurate representations of sharks targeted in the lessons and stereotype words (e.g., large) that represented concepts often associated with sharks but that are not truly representative of the group as a whole (these were items specifically targeted in the lesson plans as conventional stereotypes about sharks). The category of unclassified was used for words that were ambiguous or not clearly assignable to a category (e.g., water) (see Figure 1).

Words associated with scientists were sorted into themes using a similar flowchart. Students' words associated with scientists were first separated by emotional (e.g., boring or interesting) versus nonemotional

(e.g., experiment or biologist). Within the emotional category, words were further segregated into negative (e.g., boring) and positive (e.g., interesting). Within the nonemotional category, words were further segregated into words dealing with scientific process (e.g., experiment), equipment (e.g., chemicals), stereotyped views of scientists (e.g., white), and science content (e.g., biologist). The category of unclassified was used for words that were ambiguous or not clearly assignable to a category (e.g., people) (see Figure 2).

In addition to survey data, anecdotal evidence was collected to assess students' attitude shifts. Students from one of the partnering classes ($n = 31$) were asked to write a short comment about their experience in the shark research partnership. These comments were collected and analyzed to validate the meaning ascribed to the students' use of first-impression words in the pre and post surveys. Students' comments were read and a content analysis was conducted to develop themes reflective of the comments. After establishing themes, comments were sorted and tallied. Comments and observations made by teachers were also collected in order to assess the effect of the partnership on students' attitudes.

Results

Survey Data

The students ($N = 229$) used a total of 1,128 words to describe sharks in the pre surveys and 939 words to describe sharks in the post surveys. Of the five theme categories established for shark words (negative, positive, science content, stereotype, and unclassified, the two largest categories both pre and post survey were negative and stereotype (Table 1). Paired pre to post comparisons showed significant decreases in negative words ($p = .002$) as well as significant increases in positive words ($p = .023$) and science content words ($p < .0001$). The other categories did not show significant changes (see Figure 3).

Students used a total of 1,065 words to describe scientists in the pre surveys and 909 words to describe scientists in the post surveys. Of the seven theme categories established for scientist words (negative, positive, equipment, stereotypes, education, science content, and unclassified), the three largest categories both pre and post survey were equipment, positive, and science content (Table 2). The difference in student responses about scientists pre and post survey was not as dramatic as the difference in students' responses about sharks. There was a statistically significant decrease only in negative words ($p = .002$). No other categories demonstrated significant changes, and students' general attitude toward scientists remained relatively constant (see Figure 4).

Anecdotal Data

Shifts in student attitudes about sharks were apparent in student behavior and in written comments. Students expressed concern for the well-being of the live sharks, and they also expressed surprise at how fragile live sharks actually are. In the post-project comments collected from a subset of students (one class, $n = 31$), four expressed a newfound desire to major in marine science, seven described the partnership as an experience of a lifetime, and eight said that they had liked learning. Twelve of these students also specifically stated that their attitudes about sharks had changed. Examples of these comments about attitude shifts include

> *I also got a chance to really understand the sharks and their behavior. I realized that not all sharks are harmful. You helped me realize that, so now not all the time I could be afraid of sharks.*

> *I think I changed my mind about sharks now because I am looking at sharks in a different way makes me realize that they are not that harmful to us, but are harmful if you harm them.*

> *I now know that sharks can be nice too, it's just that I perceived them in a different way because of what I hear on the news.*

> *At first I thought sharks were mean and vicious, but now my perspective has changed a whole lot. . . . I will successfully take this knowledge and pass it on to my fellow friends and family.*

> *To tell you the truth, I was able to also teach my brother that sharks are not really all scary. Although it was kind of hard to explain, but I was able to see myself loving sharks. Now I know that they're also like other animals and us.*

Teacher comments also indicated that the students were highly engaged in the partnership project. One teacher partner commented of the animal tagging activity (see Appendix for a description of activities), "I really like this. They (the students) are actually THINKING (emphasis teacher's). It is really hard to

Table 1
*Shark Words Used by Students in Pre and Post Surveys**

Shark Words	Total	Total Pre	Total Post	Difference	Pre %	Post %	Difference	*t*-test *p* Value
Negative	608	407	201	−206	36.1	21.4	−14.7	.002
Scary/spooky/ fear/afraid	162	98	64	−34	8.7	6.8	−1.9	
Dangerous	86	60	26	−34	5.3	2.8	−2.6	
Blood	60	37	23	−14	3.3	2.4	−.8	
Killer/kill-eat people	53	44	9	−35	3.9	1.0	−2.9	
Vicious/mean/fierce/evil	47	33	14	−19	2.9	1.5	−1.4	
Dead/deadly/death	39	27	12	−15	2.4	1.3	−1.1	
Attack	36	25	11	−14	2.2	1.2	−1.0	
Bite	23	15	8	−7	1.3	.9	−.5	
Aggressive	14	9	5	−4	.8	.5	−.3	
Hurtful/harmful	10	7	3	−4	.6	.3	−.3	
Crazy	8	7	1	−6	.6	.1	−.5	
Don't swim/swim away/get out of water	8	5	3	−2	.4	.3	−.1	
Ugly	7	4	3	−1	.4	.3	.0	
Mischievous/cunning/sneaky	7	4	3	−1	.4	.3	.0	
Other	48	32	16	−16	2.8	1.7	−1.1	
Positive	237	98	139	41	8.7	14.8	6.1	.023
Cool/rad/sweet	45	22	23	1	2.0	2.4	.5	
Strong/powerful/tough	37	18	19	1	1.6	2.0	.4	
Smart/intelligent	33	7	26	19	.6	2.8	2.1	
Interesting	14	6	8	2	.5	.9	.3	
Awesome/amazing/exciting/wonderful	13	6	8	2	.5	.9	.3	
Beautiful/cute/pretty	12	5	7	2	.4	.7	.3	
Unique/special	8	0	8	8	.0	.9	.9	
Friendly/playful/nice	8	3	5	2	.3	.5	.3	
Amakua (family spirit)/Hawaiians	7	2	5	3	.2	.5	.4	
Other	59	29	30	1	2.6	3.2	.6	
Science content	283	82	201	119	7.3	21.4	14.1	.000
Fish	48	23	25	2	2.0	2.7	.6	
Big and small/different shapes	22	3	19	16	.3	2.0	1.8	
Swim/swimmers	20	11	9	−2	1.0	1.0	.0	
Cartilage/no bones	19	1	18	17	.1	1.9	1.8	

Table 1
Continued

Shark Words	Total	Total Pre	Total Post	Difference	Pre %	Post %	Difference	*t*-test *p* Value
Different types/diversity/variety	17	1	16	15	.1	1.7	1.6	
Rough skin/sandpaper	16	8	8	0	.7	.9	.1	
Fins	16	8	8	0	.7	.9	.1	
Specific part (e.g., heterocercal tail/ampullae)	16	0	16	16	.0	1.7	1.7	
elasmobranch	13	0	13	13	.0	1.4	1.4	
Specific type of shark (e.g., cookie cutter shark)	13	1	12	11	.1	1.3	1.2	
5–6 gills/open gills/gills	10	1	9	8	.1	1.0	.9	
Different colors/counter shading/camouflaged	8	0	8	8	.0	.9	.9	
Smooth/sleek	7	3	4	1	.3	.4	.2	
Other	58	22	36	14	2.0	3.8	1.9	
Stereotype	679	405	274	−131	35.9	29.2	−6.7	.059
Big/huge/large/long	192	120	72	−48	10.6	7.7	−3.0	
Teeth/large teeth	148	79	69	−10	7.0	7.3	.3	
Sharp teeth	86	57	29	−28	5.1	3.1	−2.0	
Fast	66	37	29	−8	3.3	3.1	−.2	
Predator/hunter	40	27	13	−14	2.4	1.4	−1.0	
Jaws/mouth	40	24	16	−8	2.1	1.7	−.4	
Gray	37	21	16	−5	1.9	1.7	−.2	
Meat eaters/carnivore	28	16	12	−4	1.4	1.3	−.1	
Great white shark	18	8	10	2	.7	1.1	.4	
Other	24	16	8	−8	1.4	.9	−.6	
Unclassified	260	136	124	−12	12.1	13.2	1.1	.585
Ocean/water	85	52	33	−19	4.6	3.5	−1.1	
"Jaws"	28	14	14	0	1.2	1.5	.2	
Hungry	17	9	8	−1	.8	.9	.1	
Food	9	2	7	5	.2	.7	.6	
Other	121	59	62	3	5.2	6.6	1.4	
Total words	2,067	1,128	939					

* *t*-test analysis of paired pre–post samples used percent within classes rather than the overall percent shown here. Words used less than seven times are grouped as "other."

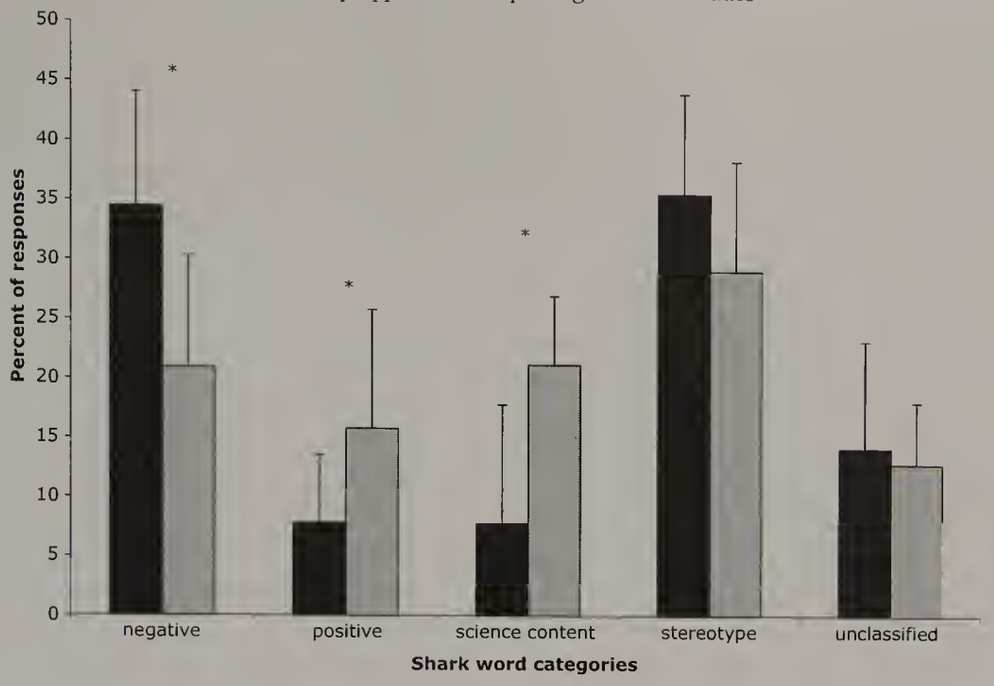

Figure 3. Relative frequency of shark words reported in student surveys. Black bars indicate the mean percent of responses by class for each category in pre surveys. Gray bars show post survey values. Error bars show standard deviations. Asterisks indicate categories with statistically significant differences between pre and post surveys ($p < .05$) in a paired *t*-test.

get them to think for themselves." Another teacher partner commented that student attendance was noticeably higher on days when the "shark lady" was scheduled to be in class. In addition, the teachers pointed out that the students who volunteered for the optional portion included students characterized as scholastically low-achieving. In fact, students who were low-performing in their classroom settings were often very competent in the field component.

Conclusions

Misconceptions About Sharks Corrected Through Exposure to a Wide Variety of Sharks

This student–teacher–scientist partnership project had demonstrable, positive effects on students' attitudes about sharks. At the end of the lesson sequence, students were more positive about sharks and they used more sophisticated scientific language in their first-impression words, which is an indication of increased content knowledge. In addition, anecdotal evidence indicated a desire among students to share their newfound knowledge with family and peer groups. Although this anecdotal evidence comes from a subset of participants and does not provide conclusive evidence of attitude shifts, it does help to validate the meaning ascribed to the first-impression word analysis and to give insight into the thoughts of student and teacher participants that was not discernable through the students' surveys alone. The anecdotal evidence presented here was also typical of comments made by students from all schools throughout the partnership.

This significant improvement in students' positive attitudes about sharks was encouraging, especially given the relatively short duration of the interaction (six class periods and four optional field experiences). This finding supports research in informal education settings (see Falk et al., 2007 and references therein), which suggests that brief exposure to novel experiences (such as zoos and aquaria) can impact students' attitudes and have lasting benefits. Therefore, the establishment of future short-term partnerships between science researchers and K–12 students and teachers appears to be a viable mechanism for influencing student attitudes, although there are limits to the influence that such partnerships may have.

The success of this particular partnership in shifting students' attitudes, for example, was likely influenced by the fact that many students' negative attitudes were rooted in a lack of exposure to different types of sharks, making it possible to directly address their gap in knowledge during the short intervention. For example, students were generally unaware that sharks and other elasmobranchs exist in a variety of sizes

Table 2
*Scientist Words Used by Students in Pre and Post Surveys**

Scientist Words	Total	Total Pre	Total Post	Pre %	Post %	Difference	*t*-test *p* Value
Negative	157	101	56	9.5	6.2	−3.3	.003
Nerd/geek/dork	26	22	21	2.1	2.3	.2	
Hard work	23	16	7	1.5	.8	−.7	
Boring/serious/no fun	20	16	4	1.5	.4	−1.1	
Insane/crazy/mad/madness	19	17	15	1.6	1.7	.1	
Know-it-all/smarty pants	8	6	2	.6	.2	−.3	
Weird/freak	8	3	5	.3	.6	.3	
Other	39	27	12	2.5	1.3	−1.2	
Positive	491	262	229	24.6	25.2	.6	.462
Smart/intelligent/bright/genious	310	169	138	15.9	15.2	−.7	
Interesting/fun	31	10	21	.9	2.3	1.4	
Hard working	20	11	9	1.0	1.0	.0	
Creative/skillful/talented/gifted	18	12	6	1.1	.7	−.5	
Cool/cool nerds	16	6	10	.6	1.1	.5	
Nice/friendly/caring/helpful	15	7	8	.7	.9	.2	
Brave/bold/fearless	11	6	5	.6	.6	.0	
Unique/one of a kind	11	7	4	.7	.4	−.2	
Other	59	29	30	2.7	3.3	.6	
Scientific process	623	326	297	30.6	32.7	2.1	.892
Study/studies/tests	113	72	41	6.8	4.5	−2.3	
Experiment	108	51	57	4.8	6.3	1.5	
Research/researchers	71	32	39	3.0	4.3	1.3	
Discoveries/discovery	29	14	15	1.3	1.7	.3	
Hypothesis/predictions	28	15	13	1.4	1.4	.0	
Curious/inquisitive	25	12	13	1.1	1.4	.3	
Exploring/explorer/adventurer	25	16	9	1.5	1.0	−.5	
Observe/observation	22	15	7	1.4	.8	−.6	
Learner/ready to learn/learning new stuff	20	9	11	.8	1.2	.4	
Knowledgeable/knowledgeable about research	17	12	5	1.1	.6	−.6	
School/classes/education	17	6	11	.6	1.2	.6	

Table 2
Continued

Scientist Words	Total	Total Pre	Total Post	Pre %	Post %	Difference	*t*-test *p* Value
Data	14	6	8	.6	.9	.3	
Inventors/inventing	12	9	3	.8	.3	−.5	
Thinking/thinkers/hard thinker	10	6	4	.6	.4	−.1	
Teacher/professor	10	5	5	.5	.6	.1	
University/college/college graduate	10	5	5	.5	.6	.1	
Evaluator/evaluate/analyze	9	4	5	.4	.6	.2	
Method/procedures/conclusion	7	2	5	.2	.6	.4	
Other	76	35	41	3.3	4.5	1.2	
Equipment	438	239	198	22.4	21.8	−.7	.554
Lab/lab work	96	50	46	4.7	5.1	.4	
Lab coat/white coat/apron	73	44	29	4.1	3.2	−.9	
Chemicals	63	41	22	3.8	2.4	−1.4	
Glassware (beaker, test tube, etc.)	37	20	17	1.9	1.9	.0	
Goggles	32	16	16	1.5	1.8	.3	
Science equipment	32	23	9	2.2	1.0	−1.2	
Microscope	25	14	11	1.3	1.2	−.1	
Math/formulas/equations	17	9	8	.8	.9	.0	
Tools/measuring tools/scale	16	5	11	.5	1.2	.7	
Technology/high tech/electronics/computer	10	5	5	.5	.6	.1	
Other	37	12	24	1.1	2.6	1.5	
Stereotyped persona	137	75	62	7.0	6.8	−.2	.648
Rich/has money/takes money	20	12	8	1.1	.9	−.2	
Glasses (wears them)	58	32	26	3.0	2.9	−.1	
TV/movie (Hulk, Star Wars, Doom, etc.)	16	8	8	.8	.9	.1	
White/Caucasian	7	3	4	.3	.4	.2	
Purple fluid/potion/explosions	7	4	3	.4	.3	.0	
Other	29	16	13	1.5	1.4	−.1	
General science	91	40	51	3.8	5.6	1.9	.597
Type of scientist (biologist, chemist, geologist, etc.)	20	10	10	.9	1.1	.2	

Table 2
Continued

Scientist Words	Total	Total Pre	Total Post	Pre %	Post %	Difference	*t*-test *p* Value
Ocean	9	7	2	.7	.2	−.4	
Name of scientist (author)	8	0	8	.0	.9	.9	
Other	54	23	31	2.2	3.4	1.3	
Unclassified	38	22	16	2.1	1.8	−.3	.933
People	8	6	2	.6	.2	−.3	
Other	30	16	14	1.5	1.5	.0	
Total words	1,975	1,065	909				

* *t*-test analysis of paired pre–post samples used percent within classes rather than the overall percent shown here. Words used less than seven times are grouped as "other."

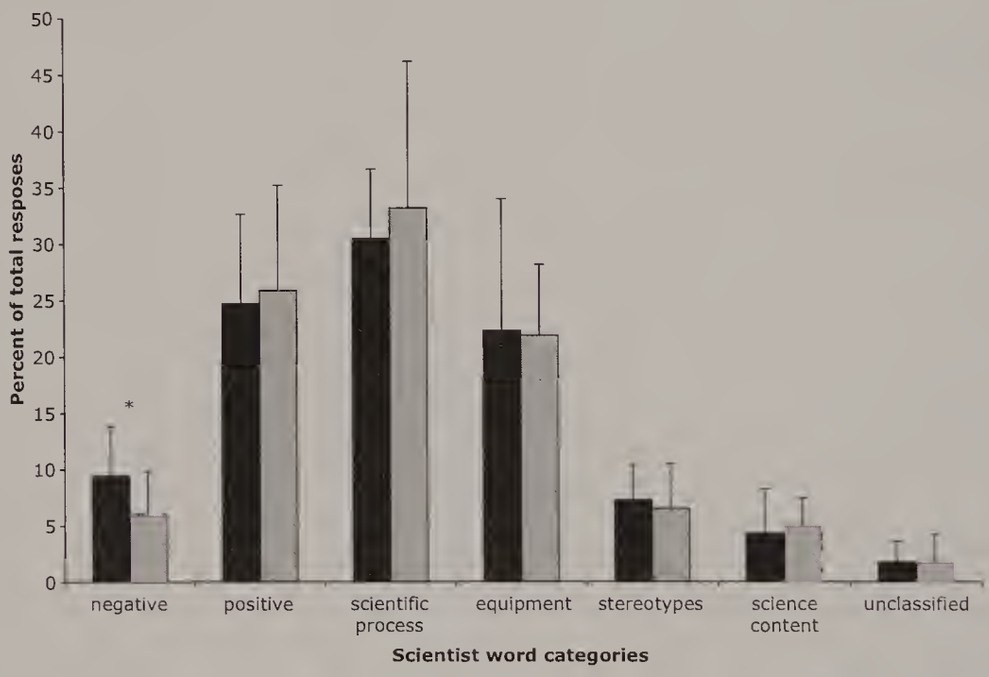

Figure 4. Relative frequency of scientist words reported in student surveys. Black bars indicate the mean percent of responses by class for each category in pre surveys. Gray bars show post survey values. Error bars show standard deviations. Asterisks indicate categories with statistically significant differences between pre and post surveys ($p < .10$) in a paired *t*-test.

(from a few centimeters to over three meters), colors (from grey to blue spotted), and lifestyles (from active predators to plankton filterers). Students were also generally unaware that even large, dangerous sharks are very fragile creatures. Through the in-class lessons, students were exposed to a variety of shark species. And, through field activities, some of the students experienced the vulnerability of sharks firsthand. Invariably, the fragile nature of sharks also became a classroom discussion topic; students were surprised that real-life sharks were vulnerable to human interaction—even when humans were trying to take good care of the sharks (i.e., in captivity). The success of students' attitude shift about sharks therefore appears to be partly a result of the relative ease of expanding their prior conception of sharks as large,

grey robust creatures when they were exposed to sharks with a variety of shapes, sizes, and colors, which necessitated a restructuring of their shark stereotype.

Despite the success in attitude shift toward positive feelings about sharks, students' post surveys continued to indicate a high proportion of fear of sharks and thoughts associated with eating and teeth. The difficulty in influencing students' feelings of fear was likely due to the deep-rooted nature of these fears. Additionally, because sharks can truly be dangerous, these stereotypes and fears are not born entirely of misconception. Thus, the inability to significantly alter students' fear of sharks is not surprising. Indeed, the difficulty in attempting to alter students' perspectives about sharks has an interesting philosophical basis. It is important to allow a healthy level of fear while at the same time helping students to understand the ecological value of sharks. In other words, the educational goal was to help students improve their attitudes toward sharks in such a way that the relative danger associated with sharks was put into perspective so that the students can act as thoughtful, informed citizens rather than irrational ones. The students' expression of concern for sharks' well-being and positive feelings toward sharks in their anecdotal comments (see student quotes above) indicate that the partnership program successfully reached at least some students on an intimate, emotional level. Nevertheless, the students' fear of sharks is something that might have required more prolonged exposure to fully address. On the other hand, the large number of student responses that dealt with eating and teeth both pre and post survey is likely also rooted in the fact that the experiment itself focused on feeding and food conversion. Thus, although the goal was for students to revise their view of sharks from stereotypical "eating machines" to a more holistic view of sharks, this effort was confounded by involving the students with a feeding experiment.

Smaller Changes in Students' Attitudes Toward Scientists

Despite the strong partnership between the scientist, the K–12 teacher, and the students, improvement in students' attitudes about scientists was not clearly evident. Students did reduce their negative word choice associated with scientists, but their overall impression of scientists was fairly positive to begin with, and students also used many words associated with scientific process, both of which were implicit goals of the partnership. However, upon examination of the actual words chosen by students, much of their positive visions of scientists indicated a disconnection between themselves and scientists (e.g., special, unique, brave, etc.). This concern is reinforced by studies looking at the glamorization of scientists in television shows such as "CSI" (see Deutsch, 2006; Duncan & Daly-Engel, 2006; Willing, 2005). In addition, although the number of responses in the scientific method category is an overall positive finding concerning student's attitudes about science, the composition of words dealt mostly with rote process (e.g., experiment, study, tests, research). Responses dealing with scientific thought and habits of mind (e.g., curious, thinking, observation) were much less frequent, even in post-evaluations. This is possibly due to the predetermined nature of the shark experiment protocol. Even though students participated in aspects of the research design and data analysis, the inquiry was not completely open ended.

Furthermore, as has been repeatedly demonstrated (see Chambers, 1983; Mead & Metraux, 1957; Thomas & Hairston, 2003), students' views of scientists in this study were closely linked to equipment (e.g., labs, lab coats, chemicals, goggles). In fact, almost 25% of scientist words dealt with equipment, both pre and post survey, even though the materials listed by students were generally not those used in the partnership research (with the exception of scales). This association of scientists with specialized and even unfamiliar equipment rather than an association with a human thinking process is fundamental to the difficulty in helping students to become scientifically literate and take ownership of their ability and obligation to effectively evaluate scientific information encountered in their daily lives.

An additional explanation for the lack of change in students' attitudes about scientists is that scientific demeanors and habits of mind were an integrated part of the partnership rather than an overt content topic addressed during the lessons. In contrast to the shark education portion of the project where students were exposed to a variety of sharks and spent a great deal of time investigating and discussing shark biology, there was not a formal emphasis placed on the diversity of scientists or the variety of methods used to do science. Rather, it was assumed that the students would see that the participating scientist was young, female, and active (rather than the stereotypic student view of a frail, elderly male) and that this would help students

better relate to this scientist in particular and science in general. Such relationships have demonstrated positive attitude shifts in previous research (see Flick 1990; Smith & Erb, 1986 who describe increased representation of female scientists in student drawings after exposure to female university scientists and graduate students). However, in this study, post-survey student responses suggest that the scientist was still not seen as "one of them"—perhaps because of differences in ethnicity between the white scientist and the majority of students who were nonwhites. This suggests that to help students identify themselves as scientists, targeted activities, discussions, and follow-up are needed on a level comparable to effort directed at other curricular concepts and skills. For the advancement of scientific literacy and science education practice, it is recommended that future research investigate how to effectively engage and reconstruct students' beliefs about scientists and strategies for incorporating such methods into partnerships and project-based learning.

Support for the Use of First-Impression Words in Attitude Assessment

The use of words to assess students' attitudes appears to be a useful method and provides an alternative to drawing tests. The use of words allowed students to relatively quickly express a variety of ideas and emotions and allowed collection of data on a topic (sharks) for which there was not a preexisting system for scoring. Although validity threats for the first-impression word method include the use of the availability heuristic (i.e., making judgments based on information that is easily brought to mind) and the presence of the stability bias (i.e., assuming that recent behaviors are typical of all behaviors), the availability of student comments helped to validate the nature of students' attitude shifts (i.e., students wrote that the experience had changed their view of sharks). In future studies, it would be beneficial to solicit student opinions about the themes used to categorize words into themes. It would also be instructive to couple the word data with questions that directly ask students to rate their attitudes pre and post partnership.

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Author's Notes

I thank the teachers and students from participating high schools in Hawaii. For the purpose of protecting privacy, they will remain anonymous. For assistance in capturing and maintaining sharks in captivity, I am indebted to a number of undergraduate and high school research assistants. I thank E. Aus, P. Breen, C. Brown, M. Burns, K. Castro, S. Crowley, J. Dale, E. Grau, S. Hada, J. Hazelhurst, L. Itano, S. Kim, M. Kay, T. Korte, A. Long, C. Olito, and E. Russo. I gratefully acknowledge E. Baumgartner, P. Brandon, L. Kaupp, T. Nguyen, F. Pottenger, and T. Seraphin for assistance in word content analysis and helpful critiques of this manuscript. Financial support for this study was provided by the ARCS foundation, the EECB NSF G-K12 program (NSF grant #05385500), the HIMB, an NSF predoctoral fellowship to the author, PADI Foundation, the University of Hawaii Curriculum Research & Development Group, and the University of Hawaii Shark Lab. This research was approved by the University of Hawaii Animal Care and Use Committee (#02-023) and by the University of Hawaii Committee on Human Subjects (CHS #16681).

Keywords: Project-based learning; GK–12; social cognitive theory; behavior.

Appendix. Grid of Concepts and Associated Questions Posed to Students in the Lesson Series. Lessons Are Aligned to the National Science Education Standards. (National Research Council, 1996)

Concept	Question	Lesson	National Science Standards
Shark biology	What makes a shark a shark?	Students create a bony fish & a shark drawing on the blackboard by taking turns adding one body part at a time.	Biological evolution
		Discuss general fish anatomy showing differing forms between bony & cartilaginous fish on blackboard drawings.	
	What senses do sharks have & how sensitive are they?	Use the blackboard drawing to talk about senses that sharks & fish have.	Behavior of organisms
		Shark senses distance game: points are marked on a string corresponding to shark senses. Students then match picture cards of shark senses to distance of sensibility.	Abilities necessary to do scientific inquiry
		Shark smell dilution experiment: students dilute lemon juice (urine) & tomato juice (blood) in parts per million to compare the point where human senses & shark senses stop detecting the two solutes.	Structure & properties of matter
	What do sharks eat?	Matching: nine types of sharks are represented by a photo of their teeth, prey, & body. Students match pictures.	Behavior of organisms
		Introduce sharks as picky eaters, differing in diet from species to species. Use examples from matching game.	Biological evolution
		Food is energy. Discuss how much food a shark needs to survive.	Matter, energy, & organization in living systems
Trophic levels & energy transfer	Where do sharks fit in the marine food web?	Who am I? Students ask yes/no questions of classmates to determine their marine organism (taped to their back) & then build a food web with string between classmates to investigate the interdependence of marine organisms on each other.	Abilities necessary to do scientific inquiry Interdependence of organisms
	How is energy transferred between organisms?	Discussion of trophic levels & energy transfer	Conservation of energy & increase in disorder
		M&M energy transfer game. One student is the shark & is at the top of the "food chain." M&Ms begin at the sun & are transferred from phytoplankton through various marine organisms, decreasing in number with each transfer.	Interactions of energy & matter Interdependence of organisms
Experiment design	How do you design an experiment?	Mind map of where food goes upon entering a shark's body.	Matter, energy, & organization in living systems
		Develop mock experiment & methods needed to investigate a question about sharks & food.	Understandings about scientific inquiry
	How do we conduct a feeding experiment on live, juvenile hammerhead sharks?	Students help brainstorm & design hypotheses & methods for this scientific study on hammerhead shark gross conversion efficiency.	Nature of scientific knowledge Behavior of organisms
		Schedule for how we will accomplish our methods, including issues of animal health & environmental quality throughout experiment.	Environmental quality
		Logistics for students coming to participate in the optional field portion with live sharks.	Science as a human endeavor

Appendix, Continued

Concept	Question	Lesson	National Science Standards
Diversity of form & function	How do you know what kind of shark, skate or ray it is? And, how are they different?	Students discuss basic form & function of sharks, skates & rays.	Biological evolution
		PowerPoint presentation on the diversity of sharks. Students observe differing color, shapes, & sizes between species, & they discuss potential adaptive advantages.	Behavior of organisms
		Shark ID: Students distinguish between different species of local sharks on a PowerPoint presentation using photo guides.	Nature of scientific knowledge
	What is your favorite elasmobranch really like and how does it survive?	Each student chooses a species of elasmobranch to research & present about.	Abilities necessary to do scientific inquiry
		Clay Shark: Students sculpt & paint a clay shark to be part of their presentation. Designed to reinforce the concept that there is variety and specificity in elasmobranch form.	Biological evolution Science as a human endeavor
		Cartoon: Students are given sample shark cartoons. As part of their research presentation, each student makes a cartoon about their chosen species or of scientists trying to understand it.	Nature of scientific knowledge
Combining cultural legends, research, & personal data	How do people feel about sharks & what do we really know?	PowerPoint presentation on shark history & public views of sharks.	Historical perspectives
		Information about shark attacks	Nature of scientific knowledge
		Results of tiger shark research conducted by scientists at the University of Hawaii.	Science & technology in local, national, & global challenges
	What did we learn in our feeding experiment with hammerhead sharks?	Review of experimental results. Students graph results, compare to hypotheses & to other classes results.	Understanding about scientific inquiry
		Class discussion of results, conclusions, & implementation of the experiment.	Science as a human endeavor
		Students present their independent research elasmobranchs (clay models & cartoons) to the class.	Nature of scientific knowledge

Development and Validation of a Computer-Administered Number Sense Scale for Fifth-Grade Children in Taiwan

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To investigate the structure of number sense and then to assess its uses in fifth-grade children's number sense development, a computerized number sense scale was developed and evaluated. The findings of the study indicate that the newly developed scale, with four dominant factors identified and reconfirmed, is internally consistent and substantially valid. It can be reliably used as a screening measure for a quick check of students' number sense development via online self-assessment. Compared with our previous study, both qualitative and quantitative changes were detected in students' number sense development at different grades. The qualitative change in number sense development is manifested in different numbers of factor components produced at different grades. The quantitative change is manifested in different amounts of factor variance explained at different grades. Furthermore, among the four aspects of number sense, Taiwanese students perform best on recognizing the relative number size yet relatively worse on judging the reasonableness of computational results.

Number sense has been internationally considered to be an important topic and plays a key role in our daily-life situation (Australian Education Council, 1991; Cockcroft, 1982; Markovits & Sowder, 1994; McIntosh, Reys, Reys, Bana, & Farrel, 1997; National Council of Teachers of Mathematics [NCTM], 2000; National Research Council, 2002). For example, the *Principles and Standards for School Mathematics* (NCTM) states that ". . . central to this standard is the development of number sense" (p. 32). Each state in Australia has developed its own numeracy enhancement programs such as *Count Me in Too/ Space/Measurement/Indigenous* (New South Wales), *First Steps* (Western Australia), and *Flying Start* (Tasmania) (Walls, 2009). No doubt, developing number sense is the new focus of mathematics education.

There is currently a significant mathematics curriculum innovation underway in Taiwan. The new *Guidelines for a Nine-Year Joint Mathematics Curricula Plan* (Ministry of Education in Taiwan, 2003) highlights that mathematics instruction should emphasize meaningful connections with real life. Even though number sense is not explicitly stated in the new guidelines, it still reflects the spirit of number sense emphasizing estimation ability, meaningful learning, and events connected to daily life. If noticeable progress in mathematics education in Taiwan is to be made, the development of number sense should play a more important role than ever in the elementary school mathematics curriculum.

Although there have been a lot of studies focusing on number sense, few formal or online instruments for assessing number sense have been developed in the past two decades. Because of the indispensable need for assessing or screening students' number sense, an online standardized number sense scale is an efficient option to help teachers and researchers reliably assess or diagnose children's development of number sense. Accordingly, this study intended to develop a reliable, valid, and efficient tool for assessing fifth-grade students' number sense development and to demonstrate what the newly developed number sense test intends to measure.

Background

Number sense, also termed as numeracy in Britain, Australia, and New Zealand, is a complex and multifaceted process involving many different characteristics of numbers, operations, and their relationships (McIntosh, Reys, & Reys, 1992; Walls, 2009). For example, in 1997 the Australian Numeracy Education Strategy Development conference described it as "The effective use of mathematics to meet the general demands of life at home, in paid work, and for participation in community and civic life" (Australian Association of Mathematics Teachers [AAMT], 1997, p. 39). It involves

> . . . a deep understanding of mathematical principles and relationships, a high degree of fluency and flexibility with operations and procedures, a recognition of and appreciation for the consistency and regularity of mathematics, and a mature facility in working with numerical expressions" (Berch, 2005, p. 333).

Because of its importance in children's numeracy development, number sense has attracted much attention from mathematics educators, researchers, curriculum designers, and local government. Thus, many researchers (Case, 1989; NCTM, 2000; McIntosh et al., 1997; Sowder, 1992) have investigated the characteristics of number sense, and many educators (Greeno, 1991; Hiebert, 1989; Resnick, 1989) have examined the number sense development from psychological perspectives. This has, in turn, encouraged many researchers (Markovits & Sowder, 1994; Yang, Hsu, & Huang, 2004) to design related activities to help children develop number sense, or to construct relevant tests to assess children's number sense.

Although different researchers or math educators may define number sense and its components quite differently (Berch, 2005; Jordan, Kaplan, Locuniak, & Ramineni, 2007; Verschaffel, Greer, & De Corte, 2007; Yang, 2005; Yang, Li, & Li, 2008), an initial most important five-factor number sense model for the fifth graders is proposed:

1. understanding the meaning of numbers;
2. recognizing relative number magnitude;
3. recognizing the relative effect of operations on numbers;
4. judging the reasonableness of computational results; and
5. being able to use multiple representations of numbers and operations (see Table 3).

The five-factor model is detailed as follows:

1. *Understanding the basic meaning of a number.* This is the ability to make sense of the base 10-number system (including whole numbers, fractions, and decimals), place value, patterns of numbers, and the four basic operations and their multiple ways of representation (McIntosh et al., 1992). For example, children should know that a number can be represented more than one way: $25\% = \frac{1}{4} = .25$.

2. *Recognizing the relative number size.* It means that children can recognize the relative size of numbers. For example, when students compare fractions, they do not need to rely on standard written algorithms, such as finding the least common denominator as suggested in the curriculum. They should be able to use some meaningful ways, strategies such as same numerator, same denominator, transitive, or residual (Behr, Wachsmuth, Post, & Lesh, 1984; Cramer, Post, & delMas, 2002) to compare the fractions.

3. *Recognizing the relative effect of operations on numbers.* This implies that an individual is able to recognize how the four basic operations affect the computational results. For example, when asking children to find the best estimate for 3,995 × .98, they do not need to rely on paper and pencil to find the answer and they should know that the answer is just a little less than 3,995 because .98 is quite close to 1. In fact, they should also understand the meaning of operations, recognizing that multiplication does not always result in a larger number, or division in a smaller value (Graeber & Tirosh, 1990; Greer, 1987).

4. *Judging the reasonableness of computational results.* It indicates that individuals can mentally apply estimation strategies to problems without using paper and pencil (McIntosh et al., 1992). At the same time, they should also be able to judge the reasonableness of the computational results. For example, compared with the 85-floor Tuntex Sky Tower, children should be able to judge that the following options are unreasonable estimates of the 85-floor tower's height: the height of Alishan mountain, which is about 2.4 km, the total height of 85 persons, or a tree, is about 50 meters high. They should know that each floor is about 3-4 meters and, therefore, 85 floors is about 300 meters. Therefore, the correct answer is the playground whose perimeter is about 300 meters is the best comparison.

5. *Being able to use nultiple representations of numbers and operations.* It implies that children are able to develop and apply different forms of representations, such as pictorial, oral, and symbolic representation of numbers and operations (McIntosh et al., 1992). For example, when children are asked to compare $\frac{7}{8}$ and $\frac{9}{10}$, they should know how to use a pictorial representation to compare them meaningfully. At the same time, they also should know how to use symbolic representation, such as the strategy of residual (Behr et al., 1984; Cramer et al., 2002) to compare these fractions.

Methodology

Sample

The 1,212 students in 47 classes who participated in this study had just completed the fifth-grade curriculum. Sampled from 21 elementary schools, both metropolitan and rural, they represent a good cross-section of Taiwan's fifth-grade population. We split the total sample approximately in half. One half was used as a calibration sample for number sense theory development and the other half as a cross-validation sample. We had selected the students from a wide range of family backgrounds such as different occupations, incomes, and educational levels. In order to check the stability of the newly developed computerized number sense test, a random sample of 228 fifth-grade students were used in a test–retest reliability assessment. The test–retest interval was about two weeks.

Instrument Development

Based on the initial five-factor number sense framework and textbooks used in Taiwan, we drafted as many as possible. We then invited four experienced math teachers in the elementary schools and two mathematics educators to review these items carefully. To ensure that we were not testing beyond the grade level, we also deleted the questions appearing inappropriate for the fifth-grade students. With a careful scrutiny, 60 items survived the first-run review.

In order to make these items more representative and item options more diagnostic in nature, in the early stage of test development, open-ended or half open-ended written questions are used to elicit errors or misconceptions often committed in solving the number sense questions. For example:

> Fill in the blank with an appropriate number: 1, 2, 3, 5, 8, 13, 21, __, 55.
>
> I think the answer is: __. Please write down your reasons as quickly as possible.

There are 140 students selected to join this pretest study. Based on the item analysis results, we delcted some items because of poor discrimination power. Accordingly, 55 items were kept for the online computer-administered test. Because of a time constraint of 40 minutes per class and the limited persistence of these young children, the test questions were divided into two parts (40 minutes per part), entailing a two-section online test. Part I consisted of 27 items and Part II, 28 items.

Once again, in order to determine whether students could fully understand each item and whether the online test could work well, we tested another 70 students in an online test. Results showed that the two-section online test worked very well and the time limit of 90 seconds for each question was appropriate. We again revised several items because of their ambiguous item content.

In addition, in order to tap students' number sense, children were requested not to take any paper and pencils into the online computer-administered testing rooms. Without paper or pencils available children are less likely to use written computation to solve problems. This is quite different from the earlier paper–pencil number sense studies (Markovits & Sowder, 1994; McIntosh et al., 1997; Reys & Yang, 1998).

Scoring Rules

For each test question, the students had to provide a correct answer and the reason for their choice. With a view of increasing score distribution and obtaining more stable ability, a special scoring rule for increasing score range was used and described below:

1. If both the answer and the corresponding reason were correct, four points were given.
2. If the answer was correct but the corresponding reason was incorrect, one point was given.
3. If the answer was incorrect but the corresponding reason was correct, two points were given.
4. If both the answer and the corresponding reason were incorrect, no score was given.

Data Analysis

We conducted an internal consistency analysis and a series of exploratory factor analyses of the number sense online test using SPSS to pick optimal items for each meaningful factor. We next conducted a confirmatory factor analysis (CFA) using AMOS 5 to select a better number sense model from two competing models. Using modification index as an aid, the selected model was modified by linking the correlated item errors if relevant.

Results

Preliminary Item Analysis

An initial item analysis for the 55 items showed that the difficulty indices were between .1518 and .8003, and the indices of item discrimination range from .0462 to .7921. Without undermining the proposed structure of number sense, eight questions were

deleted because of poor item discrimination (<.3). Thus, 47 items remained for further factor analysis.

Exploratory Factor Analysis

Out of the test results of the 1,212 investigated students, we performed an exploratory factor analysis on a sample of 591 students to further screen items and develop number sense structure. The other 621 students were used for the CFA. This helped us to explore sensible models and confirm a better number sense model. Because of the limited number of ordinal scores (categorical data) used in the students' answers, we used principle factor analysis to factorize the polychoric correlation matrix, which is computed from SAS POLYCHOR macro (version 1.3). Besides, because number sense components are related in nature, the initial components are further rotated by the promax approach to obtain a clear and simple structure. Below is the detailed item screening process via successive factor analyses. First, 30 items, their factor loadings larger than .30, were retained for the second-run factor analysis. Twenty items survived the fourth–run factor analysis after deleting cross-loading or low factor loading items.

According to Hair, Anderson, Tatham, and Black (1995), the factor pattern matrix was better on judging the specific contribution to a given factor for some items. Thus, we used the factor pattern matrix rather than the factor structure matrix to categorize items into relevant components.

Criteria for Extracting Meaningful Factors to Pick Optimal Items

For space reasons, merely the final-run factor analysis result out of 20 items was presented in Table 1 after deleting items of cross-loading (for easy interpretation), over-redundancy, or low factor loading. It reports the rotated factor pattern matrix using the Promax solution. Consequently, four items used in each subscale were determined by their factor loadings and conceptual consistency within each subscale. These 20 items were also subjected to the later CFA on another independent sample.

Based on our empirical results from the exploratory factor analysis, a five-factor number sense model was identified, as shown in Table 1.

Naming the Factors

By studying items with the highest loadings on a given factor as a cue, we were able to assign a concise and meaningful name that suggested a common theme among the salient items to each given factor.

Table 1

The Fourth-Run Rotated Factor Patterns for the First Five Factors with Promax Approach (Power = 3, N = 591)

Items	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Q13	.801				
Q10	.713				
Q9	.712				
Q14	.496				
Q6		.563			
Q5		.509			
Q4		.442			
Q21		.344			
Q29			.602		
Q30			.491		
Q33			.446		
Q32			.349		
Q55				.602	
Q50				.580	
Q43				.412	
Q45				.408	
Q16					.652
Q24					.469*
Q15	.361				.375
Q11					.327
Eigen-values explained by each factor					
	2.177	1.358	1.354	1.349	1.211

Note. Factor loadings less than .30 are suppressed. Number of items = 20.

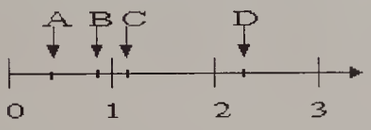
* Except in item 24, the other three items in Factor 5 are from the same proposed construct as Factor 1: "recognizing the relative number size."

Factor 1: Recognizing the relative number size. Q9, Q10, Q13, and Q14 in Factor 1 were all originally written for relative number size recognition. To give an item content example, Q9 is shown here: *Without*

using paper and pencil, please estimate which one is larger, $\frac{7}{11}$ or $\frac{7}{10}$?

1. $\frac{7}{10}$
2. $\frac{7}{11}$
3. Identical
4. Not possible to decide without computation.

Factor 2: Being able to use multiple forms of representations of numbers and operations. Q43, Q45, Q50, and Q55 in Factor 2 demand a student's ability to use multiple forms of representations of numbers and operations. To give an item content example, item Q43 is shown here: You must use a fraction to represent A, B, C, and D in the following number line. Which of the following English letters ends up having a numerator that is just a little bit greater than the denominator?



1. A
2. B
3. C
4. D

Factor 3: Judging the reasonableness of computational results. Four items, Q29, Q30, Q32, and Q33 are in Factor 3. These items were all originally postulated for judging the reasonableness of computational results. To give an item content example, item Q30 is shown here: *Without using paper and pencil*, which item option has the largest computational result?

1. 999.9×99.9
2. 999.9×999.9
3. 9999×9.99
4. 99.99×99.99

Factor 4: Understanding the basic meanings of a number. There are four questions, Q4, Q5, Q6, and Q21, in Factor 4. Except Q21, they were all originally developed for understanding the basic meanings of a number. For an example of the item content, Q21 is shown below: What is the outcome for a two-digit integer multiplied by a two-digit integer?

1. It must be a two-digit integer.
2. It must be a three-digit integer.
3. It must be a four-digit integer.
4. It must be a three-digit or four-digit integer.

It was originally designed for recognizing the relative effect of operations on numbers. After reviewing the students' selection of reasons and our earlier study (Yang et al., 2008), it was found that many students picked a four-digit integer as their answers because they thought $2 \times 2 = 4$. This is because they do not correctly understand the meaning of a two-digit integer. At the same time, some of them selected any two-digit integers to get the product, such as $10 \times 10 = 100$, so the answer is a three-digit integer. That is why this item, tapping students' knowledge about the meaning of a two-digit integer, was sorted to Factor 4 because understanding the basic meaning of a number plays a key role in solving this item.

Factor 5: Using benchmark to compare relative number size. Four items, Q11, Q15, Q16, and Q24, were categorized into Factor 5. After reviewing their contents, it was clear that students are required to use benchmark to compare relative number size to solve these more complicated problems than items in Factor 1. Thus, Factor 5 is termed "Using benchmark to compare relative number size." Most of the items in the new factor were from Factor 1, "recognizing the relative number size." These items need to apply the benchmark (such as 1 or 1/2) to compare the relative number size. In reviewing the pilot study and earlier studies (Reys & Yang, 1998; Yang & Reys, 2002), we found that most of students cannot apply the benchmark to solve these problems. They often tried to use written computation to compare relative number size. For example, when they were asked to compare $\frac{4}{5}$ and $\frac{11}{12}$ (Q11), $\frac{6}{12}$ and .4988 (Q15) or .48, $\frac{8}{15}$, $\frac{17}{16}$ (Q16), they usually tried to transfer the fractions to decimal or transfer the decimals to fractions and found the common denominators. At the same time, there are not many activities in the regular math classes to guide children how to apply the benchmark to solve problems of this kind. Therefore, these items were split into two factors (Factor 1 and Factor 5) because the expected strategy suggested by the researchers to solve some of these items is different from the strategy used by the investigated children.

Because of the heavy overlapping of Factor 1 and Factor 5, a newly identified four-factor model of number sense without the Factor 5 included deems feasible. Consequently, if the five-factor model were adopted, 20 items would be retained, while if the four-factor model were adopted, only 16 items would be retained. We tested the four competing models using CFA in order to decide best fit model using the

second sample of 621 subjects. The best fit model was further subjected to model modification if its change is meaningful.

CFA

Before performing CFA, it is necessary to test if the raw data conforms to a multivariate normal distribution (Kline, 1998). As the AMOS output shows, the skewness of studied variables falls between −1.451 and 1.133 and the kurtosis of each studied variable falls between −1.944 and .300. As a rule of thumb, skewness index values greater than 3 and kurtosis index values greater than 8 are considered unacceptable. In our data, the assumption of multivariate normality was not seriously violated (multivariate kurtosis = 5.562, CR = 1.994, $p > .01$). Therefore, no variable was removed or transformed.

In order to evaluate whether the four-factor model (16 items), or the five-factor model (20 items) is better, AMOS Basic was applied to the second sample ($N = 621$) for a CFA. Again, a polychoric correlation matrix with standard deviations was used as an input to the CFA analysis. In order to assess these two models comprehensively, we reported different descriptive and approximate measures of model fit, as reported below. If necessary and relevant, some pairs of error terms in these models were set free using modification indices larger than 10 as the threshold for model modification. Adding correlated errors were done one at a time until there were no modification indices larger than 10.

Evaluating the Overall Model-Data Fitness and Absolute Fit Measures

Specifically, χ^2, p value, *NCP*, *GFI*, *SRMR*, *root mean square error of approximation* (*RMSEA*), *AIC*, and *ECVI* were used in the study to evaluate the competing models. Data in Table 2 show that the overall model-data fit of the four proposed models was not good enough ($\chi^2 = 216.547$ and 371.697, respectively, for model A and model B; $p < .001$), indicating that neither model satisfactorily fits the data. Yet this might be because of the large sample sizes used ($N = 621$) because a χ^2 test is quite sensitive to sample size.

Thus, *NCP* and *df* were used to compute the statistical power for each model. The statistical power for each model was found to be close to 1. Therefore, the following absolute indices of fit were used to objectively compare models. The cutoff criterion in this research was .90 or higher for the *GFI* combined with a cutoff value of .06 or less for the RMSEA. The greater the *GFI*, the better is the overall model goodness of fitness. Data in Table 2 indicate that the *GFI*s (.959 and .948) for models A and B exceed the

Table 2

Fit Indices Statistics for the Four-Factor and Five-Factor Number Sense Models (N = 621)

Overall fit	x^2	p value	x^2/df	*df*	*NCP*	*GFI*	*SRMR*	*RMSEA*	*ECVI*
A) Four-factor (16 items)	216.547	.0001	2.461	88	128.547	.959	.037	.049	.504
B) Five-factor (20 items)	371.697	.0001	2.546	146	225.697	.948	.039	.050	.806

Incremental Fit	*AGFI*	*TLI*	*NFI*	*CFI*
A) Four-factor (16 items)	.937	.941	.929	.956
B) Five-factor (20 items)	.926	.914	.897	.934

Parsimonious Fit	*AIC*	*CAIC*
A) Four-factor (16 items)	312.547	573.251
B) Five-factor (20 items)	499.697	847.302

Note. Correlated errors have been taken into account in these two models (*MI* > 10).

minimum threshold of .90 as suggested by Hu and Bentler (1999). In addition, with a correlative matrix as an input, it is better that the standardized *SRMR* be less than .05. Data in Table 2 reveal that the *SRMR* statistic values of .037 and .039 for both models, and the *RMSEA* of .049 and .050 for both models, fell beyond the acceptable range of goodness of fit. The *ECVI* is suitable for evaluating competing models; if a model goes with a smaller *ECVI*, it is better. The smallest *ECVI* value of .504 went with model A. Obviously, the proposed 16-item four-factor model (model A) performed better than the 20-item five-factor model.

Incremental Fit Measures

Table 2 displays several relative fit indices for each of the four competing models. The 16-item four-factor model (model A) achieved better fit on all four indices (*AGFI* = .937, *TLI* = .941, *NFI* = .929 and *CFI* = .956) than the 5-factor mode (*AGFI* = .926, *TLI* = .914, *NFI* = .897 and *CFI* = .934). The cutoff criterion in this research was .90 or higher for the incremental fit measures. Again, the better model-fit was obtained by the modified four-factor model.

Parsimonious Fit Measures

In Table 2, two parsimonious fit measures, *AIC* and *CAIC*, were used to pick a concise model. The *AIC* value of the four-factor model (312.547) was less than the *AIC* values of 499.697 from model B. The *CAIC* value of the four-factor model (573.251) was less than the *AIC* values of 847.302 from model B. Therefore, the four-factor model was the concise model.

Except for the overall model fit χ^2 test, the fit of the modified four-factor number sense model was excellently superior to the five-factor model no matter what aspect of consideration is concerned. Therefore, the 16-item four-factor model proposed as the underlying structure model of number sense for the fifth-grade students is appropriate and adequate.

Second-Order Factor Analysis

The proposed four factors for the number sense test are highly related, indicating that a higher order factor may exist. A second-order factor analysis shows that the standardized factor loadings of the four factors (.748 .747, .866, and .881) are high, which are greater than a minimum threshold of .7. Thus, it reveals that the number sense test score has high convergent validity. The second-order factor is the general multidimensional ability construct called "number sense."

Reliability Analysis

The test of reliability for the online four-factor model includes internal consistency coefficients, construct reliability, and test–retest reliability. The internal consistency reliability using Cronbach's method was satisfactory with an alpha value of .810 on the final 16-item test. Based on *CFA* factor loadings, construct reliability of the four subscales were computed as follows: .825, .675, .672, and .694. The construct reliability for the whole scale was .886 and the average variance extracted was .660. Generally speaking, the construct reliability should be greater than .70 and the average variance extracted should be greater than .50. This reveals that the scores on the newly developed scale as a whole has good internal consistency and construct reliability. As a subscale, a user might be cautious on interpreting the scores, especially on the latter scales. Yet we are not too concerned about moderate reliability with the subscales because exceeding a certain point of reliability may undermine validity (Cattell, 1965).

In order to check if the online test is stable over time, 228 students were selected to join the test–retest reliability test over an interval of about two weeks. Results showed that the test–retest reliability for the online test was .832. The values of the test–retest reliability for each subscale were .605, .788, .557, and .512, respectively. It shows that the test–retest for each subscale was not good enough. The low correlations may have been due to limited test length or limited score range, which could have caused range restriction.

Validity Analysis

Except the content examination of the drafted test items conducted by the math educators and math teachers as shown in the instrument development section, the scale construct validity is demonstrated in the consistent four-factor structure of number sense via the CFA. The second-order factor analysis also confirms that the proposed four factors are an adequate description of fifth-grade students' number sense, indicating high convergent validity.

Summary

With empirical evidence, the four-factor number sense model for students who have completed the fifth-grade courses is reasonable. Table 3 displays different patterns of component reorganization between the five-factor model proposed by Yang et al. (2008) for students who have completed the third-grade math courses and the present four-factor model for the

Table 3
Component Shifts Between the Third and the Fifth Graders (Factors Ordered by Explained Variance)

Number Sense Components for the Third-Grade Students	Proposed Number Sense Model	Number Sense Factor Components for the Fifth-Grade Students
Factor 1: understanding the basic meaning of a number	Factor 1: understanding the basic meaning of a number	Factor 1: recognizing the relative number size
Factor 2: being able to use multiple representations of numbers and operations	Factor 2: recognizing the relative number size	Factor 2: being able to use multiple representations of numbers and operations
Factor 3: being able to decompose and compose numbers	Factor 3: recognizing the relative effect of operation on numbers	Factor 3: judging the rationality of computational results
Factor 4: judging the rationality of computational results	Factor 4: judging the rationality of computational results	Factor 4: understanding the basic meaning of a numbers
Factor 5: recognizing the elative number size	Factor 5: being able to use multiple representations of numbers and operations	

Note. Each component for the third and fifth graders is displayed in descending order by explained variance (i.e., factor importance).

fifth-grade students. Data indicated that the number sense test developed for the third graders and the fifth graders both include recognizing the relative number size, judging the reasonableness of computational results, and being able to use multiple representations of numbers and operations.

Yet the number sense component, called *understanding the basic meaning of a number*, which was included in the early study of Yang et al. (2008) as the most important factor, was shifted to Factor 4 and became less important in the present four-factor model. In reviewing the number sense related research (Markovits & Sowder, 1994; Reys & Yang, 1998) and the documents reported by the NCTM (2000) and the Ministry of Education in Taiwan (2003), "understanding the basic meaning of a number" should play an important role at each grade level, especially for the early stage of mathematics learning, as shown in our earlier study (Yang et al., 2008). With students' gradual growth and accumulation of mathematics knowledge, "understanding the basic meaning of a number" became a minor role; but that does not mean it is not important anymore for the fifth-grade students. It is turned into a basic ingredient of the other number sense factors. As Sowder and Schappelle (1994) put it: "The most important single element of number sense is an understanding of numbers" (p. 342). Based on knowledge of understanding the basic meaning of a number, students are able to acquire and develop more difficult and subtle mathematics knowledge as they grow up.

It is also worth noting that the factor *recognizing the relative number size* has shifted from the least important factor for the third graders to the most important factor for the fifth graders. This may be because major topics in the Taiwanese textbooks used in the fifth grade put more emphasis on comparing rational numbers. Therefore, the factor relative importance of number sense was reshuffled between third and fifth grades because students at the lower grade levels begin to construct a basic understanding of numbers, while students at the higher grade levels are required to use the basic number knowledge to solve questions related to a number size (Griffin, 2004).

Furthermore, the original proposed factor, *recognizing the relative effect of operations on numbers*, turned out to be a trivial factor in the present study. It is because "recognizing the relative effect of operations on numbers" became less important when the fifth-grade students tried to solve more complicated number sense problems. Therefore, it is diluted to other factors. Salient qualitative and quantitative changes from the third grade to the fifth grader appear (see Table 3). The qualitative change is manifested in different factor

Table 4
The Descriptive Statistics for Each Number Sense Component (N = 1,212)

Factor	Number of Items	Mean* (%)	Skewness	Standard Deviation
1. Recognizing the relative number size	4	10.952 (68.4%)	−.604	4.940
2. Being able to use multiple presentations of numbers and operations	4	6.242 (39%)	.439	4.820
3. Judging the reasonableness of computational results	4	5.702 (35.6%)	.720	4.771
4. Understanding the basic meaning of a number	4	7.421 (43.4%)	.239	4.951
Total	16	30.50 (47.6%)	.321	14.480

* *Note.* All subscales measured on a four-point scale.

components. The quantitative change is reflected in factor variance extracted or factor importance.

Table 4 summarizes the descriptive statistics of each component for the fifth-grade students' performance on the number sense scale. The average performance of the investigated students was 30.50 (below the mean score of 32.00). This indicates that these students did not do well on the number sense test in terms of criterion-referenced standard.

To explore the relative weakness and strength in students' number sense development, a multivariate analysis was conducted using SPSS. The tests of Pillai's Trace and Wilks' Lambda, indicated that there is a significant difference between different components ($F = 431.685$, $df = (3,1209)$, $\alpha = .05$, with $\eta^2 = .517$). Based on pair-wise post hoc comparisons, six paired comparisons were tested and found all significantly different. Results indicate that students performed best on *recognizing the relative number size* ($\bar{x} = 10.952$) and least well on judging the reasonableness of computational results ($\bar{x} = 5.702$). We suspect that students' better performance on recognizing the number size might be due to having more examples of number size discussed in their textbooks. Their poor performance on judging the reasonableness of computational results might be due to fewer drills or practices on this aspect offered in their textbooks. This finding is consistent with earlier studies (Hsu, Yang, & Li, 2001; Yang et al., 2008). This reveals that the textbook editors and teachers in Taiwan should put more effort into teaching students how to judge the reasonableness of computational results.

Conclusion

Through a careful review of item contents and item analysis, the total scores on the newly developed computerized number sense scale is both stable ($\alpha = .810$, construct reliability = .890, and test–retest reliability = .832) and valid (validated with specialist review and content validity). It can be reliably used in a quick check of students' number sense development via online self-assessment. This study has demonstrated that the four-factor number sense model fits better than the proposed five-factor model in the description of number sense structure. But this depends on what aspects of number sense are deemed important by the test developer, and it needs a cross-validation on another representative sample. For the fifth-grade students, the key number sense components are recognizing the relative number size, being able to use the multiple forms of representations of numbers and operations, judging the reasonableness of computational results, and understanding the basic meaning of numbers. The four-factor model developed in this study is partially consistent with the earlier study for the third-grade students (Hsu et al., 2001). Four factors emerged repeatedly in all three studies of number sense at different grades: recognizing the relative number size, being able to use multiple forms of representations of numbers and operations, judging the

reasonableness of computational results, and understanding the basic meaning of a number. It implies that these four number sense components should be covered in grades 3 and 5 math textbooks. At each grade, an adjustment should be made as to the extent to which each of the four shared components should be taught.

Data also indicate that the fifth-grade students perform best on *recognizing relative number size* and perform worst on judging the reasonableness of computational results. This finding is consistent with previous studies of Hsu et al. (2001). It shows that Taiwanese students at the third grade and at the fifth grade seem relatively quite weak on the judgment of the reasonableness of computational results. Three number sense components, recognizing the relative number size, being able to use multiple representations of numbers and operations, and judging the reasonableness of computational results, are common factors in the online number sense test. Interestingly, the newly established four-factor model does not include one of the initial proposed factors called "the relative effect of operations on numbers" because it is less critical for fifth graders to solve more complicated number sense items. The apparent changes in number sense development from the third grade to the fifth grade are due to the relative importance of number sense components at different grade levels and their attribution to different major topics and content taught at each grade level. For example, the most important component, "understanding the basic meanings of a number," in grade 3, was ranked as Factor 1. This is due to the understanding of the basic meanings of numbers (including whole numbers, fractions, and decimals) being the key issue in lower grade levels. However, the same factor in this study for the fifth grade was shifted to Factor 4 in that it was less important, the implication being that it becomes diluted into other number sense components. Obviously, these qualitative and quantitative changes of number sense development are manifested in different factor components as well as factor importance at different grades as students progress through the grades. This might imply what aspects of number sense should be taught and which component should be learned first at each grade. This helps teachers work out a more effective intervention program. In addition, for cross-country study purposes, a newly developed number sense testing system (both Chinese and English versions) has been available via the following IP: http://140.130.46.2:8080. Interested researchers or educators can contact Dr. Yang for more details.

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Authors' Notes

This research is part of our project sponsored by the National Science Council, Taiwan (Grant number NSC-96-2522-S-415-001). Any opinions expressed are those of the authors and do not necessarily reflect the views of the National Science Council, Taiwan.

Keywords: Computerized scale; fifth graders; number sense; factor analysis. Dr. Yang's e-mail address is dcyang@mail.ncyu.edu.tw or contact Dr. Li at fredli@mail.ncyu.edu.tw.

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to: Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to 972-86-477-648. Questions concerning proposals and/or solutions can be sent e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before June 15, 2010.

• **5110:** *Proposed by Kenneth Korbin, New York, NY*

Given triangle ABC with an interior point P and with coordinates $A(0, 0)$, $B(6, 8)$ and $C(21, 0)$. The distance from point P to side $\overline{AB}$ is a, to side $\overline{BC}$ is b, and to side $\overline{CA}$ is c where $a:b:c = \overline{AB}:\overline{BC}:\overline{CA}$.

Find the coordinates of point P.

• **5111:** *Proposed by Michael Brozinsky, Central Islip, NY*

In Cartesianland where immortal ants live, it is mandated that any anthill must be surrounded by a triangular fence circumscribed in a circle of unit radius. Furthermore, if the vertices of any such triangle are denoted by A, B, and C, in counterclockwise order, the anthill's center must be located at the interior point P such that

$$\angle PAB = \angle PBC = \angle PCA.$$

Show $\overline{PA} \cdot \overline{PB} \cdot \overline{PC} \leq 1$.

• **5112:** *Proposed by Juan-Bosco Romero Márquez, Madrid, Spain*

Let $0 < a < b$ be real numbers with a fixed and b variable. Prove that:

$$\lim_{b \to a} \int_a^b \frac{dx}{\ln \frac{b+x}{b+x}} = \lim_{b \to a} \int_a^b \frac{dx}{\ln \frac{b(a+x)}{a(b+x)}}.$$

• **5113:** *Proposed by Paolo Perfetti, Mathematics Department, Tor Vergata University, Rome, Italy*

Let x, y be positive real numbers. Prove that

$$\frac{2xy}{x+y} + \sqrt{\frac{x^2+y^2}{2}} \leq \sqrt{xy} + \frac{x+y}{2} + \frac{\left(\frac{x+y}{6} - \frac{\sqrt{xy}}{3}\right)^2}{\frac{2xy}{x+y}}.$$

• **5114:** *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

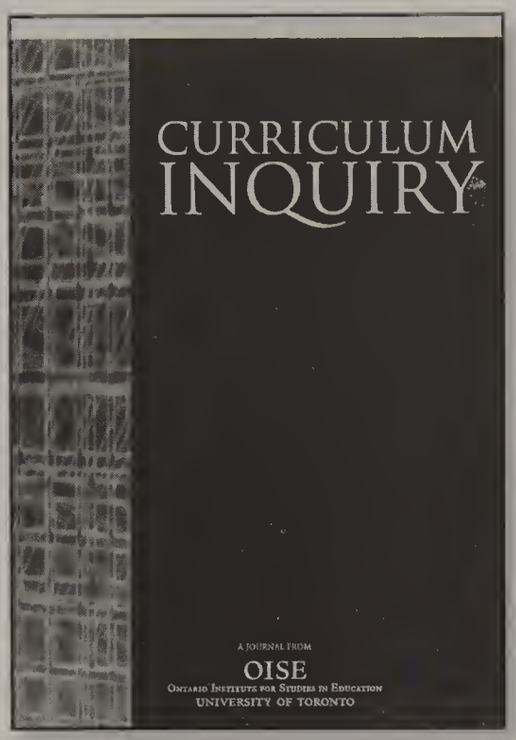
Let M be a point in the plane of triangle ABC. Prove that

$$\frac{\overline{MA}^2 + \overline{MB}^2 + \overline{MC}^2}{\overline{AB}^2 + \overline{BC}^2 + \overline{CA}^2} \geq \frac{1}{3}.$$

When does equality hold?

• **5115:** *Proposed by Mohsen Soltanifar (student, University of Saskatchewan), Saskatoon, Canada*

Let G be a finite cyclic group. Compute the number of distinct composition series of G.



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Edited by
NICHOLAS C. BURBULES

Published on behalf of the College of Education at the University of Illinois at Urbana-Champaign and co-sponsored by The John Dewey Society, the Philosophy of Education Society, and the College of Education at the University of Illinois at Chicago

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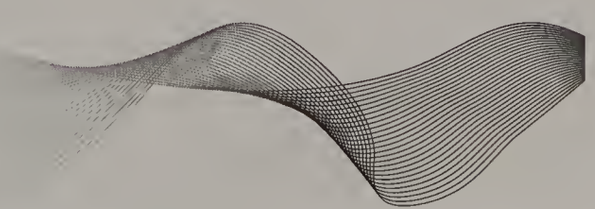

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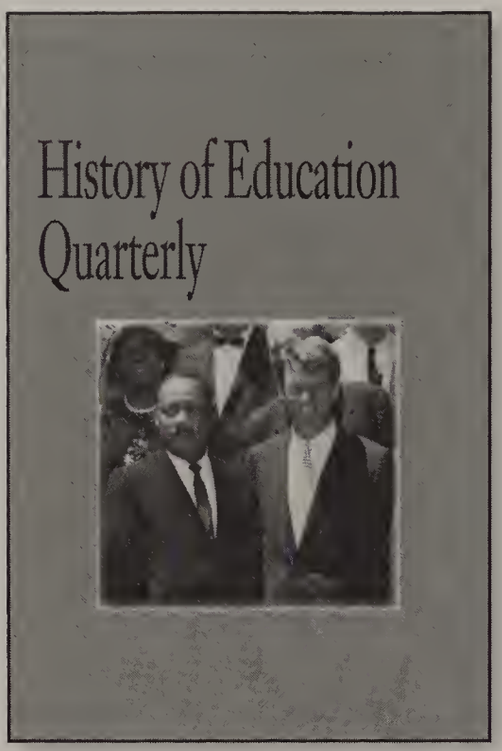

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Edited by
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School Science and Mathematics Journal
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College Station, TX 77843-4232

Circulation Data:
Reader: K-graduate leaders and teacher educators
Frequency of issue: 8 times per year
Copies per issue: 3001-4000
Sponsorship: Professional organization

Publication Guidelines:
Manuscript length, 6-25 pages, including references

Review Information:
Type of review: Blind review
No. of external reviewers: Three
No. of in-house reviewers: Up to three
Fees charged to review: None
Editor considers recommendations of reviewer: Yes
Time to review: 6-7 months
Reviewers' comments: Yes
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Results related to professional practice and literature
Enough information to enable replication (quantitative)

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SCHOOL SCIENCE AND MATHEMATICS

Volume 110 • Number 5 • May 2010

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Official Journal of the School Science and Mathematics Association, Founded 1901

School Science and Mathematics

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School Science and Mathematics (Print ISSN: 0036-6803, Online ISSN: 1949-8594) is published in January, February, March, April, September, October, November and December on behalf of the School Science and Mathematics Association by Wiley Subscription Services, Inc., a Wiley Company, 111 River St., Hoboken, NJ, 07030-5774. Periodical postage paid at Hoboken, NJ and additional offices.

Postmaster: Send all address changes to *School Science and Mathematics*, Journal Customer Services, John Wiley & Sons, Inc., 350 Main St., Malden, MA 02148-5020.

Information for Subscribers: *School Science and Mathematics* is published in eight issues per year. Subscription prices for 2010 are: Institutional Print & Online rate: US$250 (the Americas), US$250 (Rest of World), €180 (Europe) £153 (UK). Prices are exclusive of tax. Asia-Pacific GST, Canadian GST and European VAT will be applied at the appropriate rates. For more information on current tax rates, please go to www3.interscience.wiley.com/aboutus/journal_ordering_and_payment.html#Tax. The institutional price includes online access to the current and all online back files to January 1, 1997, where available. For other pricing options, including access information and terms and conditions, please visit www.interscience.wiley.com/journal-info.

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Electronic Access: This journal is available online at *Wiley InterScience*. Visit www.interscience.wiley.com to search the articles and register for table of contents and email alerts.

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ISSN: 0036-6803 (Print)
ISSN: 1949-8594 (Online)
Printed in the US by The Sheridan Group.

IN THIS issue

Research in Brief

Integrating Literature in Mathematics: A Teaching Technique for Mathematics Teachers

Elsa C. Ruiz, Jenifer Salter Thornton, Kimberley K. Cuero

The integration of content areas is not a new concept (Moyer, 2000). Integration is promoted by many teacher educators because of its benefits for learners of all ages and backgrounds (Burns, 2005; Douville, Pugalee, & Wallace, 2003; Pica, 2002). For example, bilingual students benefit from integration of content areas because of the natural repetition and contextualized scaffolding of key vocabulary and concepts (Mohr, 2004). Oftentimes, however, content areas (e.g., mathematics, science, social studies) are taught in isolation and not integrated. The high stakes-testing climate encourages attempts to parcel out knowledge into decontextualized bits and pieces, which can undermine critical thinking as well as cross-curricular connections (Bossé & Faulconer, 2008; Cobb, 2004; Czerniak, Weber, Sandmann, & Ahern, 1999).

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Reflections on Success and Retention in Urban Science Education: Voices of Five African-American Science Teachers Who Stayed

Pamela Fraser-Abder

This study highlights the factors that contribute to excellence in urban science teaching as pinpointed by five urban African-American science teachers who have taught successfully in the urban system for over 10 years. These teachers shared their experiences and reflections on the qualities that contributed to their success and persistence as urban science teachers. Their ability to understand and care for their students was a major contributing factor; other contributing factors included in-depth knowledge and love of science, caring and commitment to the whole child, effective classroom management strategies, high expectations and motivation of their students, and an understanding and acceptance of the varying parental involvement in the educational decisions about their child.

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The NCTM Process Standards and the Five Es *of Science: Connecting Math and Science*

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The Rise and Fall of Science Education: A Content Analysis of Science in Elementary Reading Textbooks of the 19th Century

Peter Rillero

In the 19th century the textbook dominated the curriculum and methods of instruction. The most

important textbook was the textbook of reading known as the reader. In the early 1800s science was not established as a separate primary grade subject. The science students encountered in these reading textbooks may have been their only formal science education. This study used content analysis to determine the type of science and quantity of science in popular U.S. readers of the 19th century. The percent of science rose in the middle of the century and declined at the end. This decline may have been because of the desire to make the study of reading literary based. The percentage of science that was biological increased throughout the century, and the percentage of earth science declined.

RESEARCH IN
brief

Elsa C. Ruiz
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Integrating Literature in Mathematics: A Teaching Technique for Mathematics Teachers

The integration of content areas is not a new concept (Moyer, 2000). Integration is promoted by many teacher educators because of its benefits for learners of all ages and backgrounds (Burns, 2005; Douville, Pugalee, & Wallace, 2003; Pica, 2002). For example, bilingual students benefit from integration of content areas because of the natural repetition and contextualized scaffolding of key vocabulary and concepts (Mohr, 2004). Oftentimes, however, content areas (e.g., mathematics, science, social studies) are taught in isolation and not integrated. The high stakes-testing climate encourages attempts to parcel out knowledge into decontextualized bits and pieces, which can undermine critical thinking as well as cross-curricular connections (Bossé & Faulconer, 2008; Cobb, 2004; Czerniak, Weber, Sandmann, & Ahern, 1999).

Literacy in general, but reading in particular, is important across the content areas. Mathematics teachers who integrate literature into mathematics recognize that mathematical understanding involves reading and writing. Conversely, mathematical reasoning and problem solving can be found in authentic reading and writing materials (Moyer, 2000). The National Council for Teachers of Mathematics (NCTM, 2000) *Principles and Standards for School Mathematics* suggested that mathematics connections to other disciplines and real-life experiences within mathematics classrooms give students a greater command of mathematics and advised teachers to plan lessons that integrated mathematics with other subject areas and real-life content. For contemporary literacy educators, there has been a consistent and ardent appeal to integrate reading and writing across various content areas. For mathematics educators and professional organizations, the integration of reading and writing are promoted but are often presented simply as "tools for learning and understanding" mathematics (Draper & Siebert, 2004, p. 928). Undoubtedly, there is confusion regarding the goal of integrating literacy and mathematics instruction. Bossé and Faulconer (2008) summarized this uncertainty as reading and writing about mathematics versus reading and writing in mathematics. In their study, Draper and Siebert advocated partnerships between literacy and mathematics educators that promote "meaningful literacy instruction" in mathematics education. Ideally, these collaborations could promote not only the use of reading and writing to gain mathematical understanding but also using mathematics as a means by which to become more proficient in reading and writing, especially reading and writing that pertains to mathematics.

Project Creating Independence Through Student-Owned Strategies (CRISS), a successful educational reform in Montana (Santa, 1996), was an attempt for school districts to change their focus from rote memorization to deep learning of content area subjects, including mathematics for secondary students by developing mathematical concepts through the use of reading, writing, listening, and discussing mathematical concepts. Mink and Fraser (2005) adapted Project CRISS for the elementary school level and renamed it Project Science and Mathematics Integrated with Literacy Experiences (SMILE). Through the implementation of Project SMILE in fifth-grade mathematics classrooms studied, researchers were able to investigate the classroom environment and students' attitudes toward reading, writing, and mathematics by providing teachers with five professional development sessions and by asking teachers to implement what they learned in these sessions in their own mathematics classrooms. They found that Project SMILE, just like Project CRISS, helped increase students' interest and confidence in learning mathematics. In addition, they observed that the teachers became more secure with teaching mathematical content and began using children's literature in their lessons.

Proficiency in the area of literacy is critical in the understanding of all content areas, including mathematics. In fact, lack of literacy proficiency with mathematics-related texts has been cited as a reason for poor performance in the area of mathematics (Mink & Fraser, 2005). Research indicated that in the area of mathematics, U.S. teachers were not proficient in integrating content areas, instead relying mostly on lecture, worksheets, and textbook problems to teach students mathematics (Hiebert et al., 2003; Wallace & Clark, 2005). This stands in direct opposition to mathematics reforms (NCTM, 2000) that promoted a more constructivist stance in the teaching and learning of mathematics and encouraged students to ask questions and investigate the world around them.

Draper (2002) referred to mathematics and literacy as "inseparable" in constructivist classroom settings. One way to promote reading and writing within the content area of mathematics is by creating print-rich environments, explicitly teaching text structure, and by addressing relevant vocabulary (Bossé & Faulconer, 2008). For middle-school and young children in particular, the vivid pictures found in some books can function as important concrete instructional materials in the learning and understanding of mathematics (Miller, 1998; Moyer, 2000). Rushton and Larkin (2001) stated that symbolic representations like letters and numbers were better learned if they could be linked or connected to vivid visual images such as pictures. Children's books can be helpful not only in developing understandings about vocabulary and text structure but also in conceptualizing abstract mathematical concepts.

Despite the many benefits of cross-content integration, there exists a great "need for professional development that assists teachers in changing their conceptual perspectives to integration while also building pedagogical knowledge related to integration of science, mathematics, and literacy" (Douville et al., 2003, p. 388). There are numerous opportunities to expound upon and investigate mathematical knowledge and understanding through reading and writing. However, in many elementary and secondary schools, mathematics and literacy instruction is oftentimes separated into two distinct areas without much overlap. Similarly, many preservice teachers do not have opportunities to see content integration and are not specifically taught how to integrate curricular content during their teacher training programs. The challenge, then, is to prepare mathematics teachers to integrate mathematics and literacy in a way that not only promotes students' understandings and appreciation of reading and writing but also deepens mathematical conceptualization.

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Reflections on Success and Retention in Urban Science Education: Voices of Five African-American Science Teachers Who Stayed

Pamela Fraser-Abder
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This study highlights the factors that contribute to excellence in urban science teaching as pinpointed by five urban African-American science teachers who have taught successfully in the urban system for over 10 years. These teachers shared their experiences and reflections on the qualities that contributed to their success and persistence as urban science teachers. Their ability to understand and care for their students was a major contributing factor; other contributing factors included in-depth knowledge and love of science, caring and commitment to the whole child, effective classroom management strategies, high expectations and motivation of their students, and an understanding and acceptance of the varying parental involvement in the educational decisions about their child.

Retention of experienced and qualified science teachers continues to be a major problem in most urban cities. The shortage is especially acute in hard-to-staff urban and rural schools. According to a 2007 MetLife issue brief, more than 1 million teachers are reaching retirement age and over the next decade it is predicted that we will have to hire more than 2 million new teachers. Although there is a great deal of focus on the need to recruit new teachers, not enough focus is being placed on retaining quality teachers already in the classrooms. In urban districts, close to 50% leave the profession during their first five years. Each teacher who is recruited, trained, and lost costs districts up to $50,000 (Portner, 2005). Additionally, when they leave, years of institutional knowledge, teaching experience, and classroom skills are lost. According to a 2004 staff report of a large urban city, over 70% of the most experienced teachers (those with 25 or more years of teaching experience) are likely to retire over the next two years. Over 26% of midcareer teachers and over 29% of new teachers say it is unlikely they will continue to teach in the city in three years. Nationally, mathematics and science teachers are significantly more likely to move from or leave their teaching jobs because of job dissatisfaction than are other teachers (40% of mathematics and science and 29% of all teachers). The United States faces a critical shortage of qualified mathematics and science teachers and will require an additional 283,000 teachers in secondary school settings by 2015 (National Center for Education Statistics, 2005). Given these statistics, it is critical that the science education community explore and develop appropriate and effective recruitment and retention strategies for urban teachers. The first stage of this exploration could involve an examination of the characteristics of science teachers who persist in the urban setting in spite of the odds. The science teacher education community needs a better understanding of the issues surrounding science teacher success and persistence if we are to recruit and retain science teachers and to achieve the goal of "scientific literacy for all." Although there is an increasing body of research on urban science education (Barton, 2001; Darling-Hammond, 1997; Jeanpierre, 2007), there still exists a need to investigate the factors associated with the recruitment, preparation, and retention of science teachers in urban communities (Fraser-Abder, Atwater, & Lee, 2006). In the field of science education, few studies have focused on factors that impact the success and persistence of African-American urban science teachers. It is important to understand the reasons that teachers remain teaching in the urban setting and the elements that contribute to their success and persistence in spite of better working conditions and increased salaries that are possible in other settings.

Problem and Research Question

According to a recent report from the National Assessment of Educational Progress (2006), student performance in urban public schools was not only poor but also far short of science scores in the nation as a whole; at least half of eighth graders tested in science failed to demonstrate even a basic understanding of the subject. In the urban setting, student poverty, parent education, home resources, English-language proficiency, and other factors outside the control of

science teachers work in tandem like a perfect storm to dampen the results in ways that few other subject areas experience (Schemo, 2006). Once many urban students enter science classrooms, they are poorly prepared and are taught by few qualified teachers. Teachers themselves must often operate in an environment where isolation and a lack of agency and school support make effective teaching a difficult and sometimes impossible feat (Fraser-Abder, 2001). In this setting teachers have to utilize pedagogy that is appropriate for students who score the lowest on national science and mathematics achievement tests. Countless studies, as well as the No Child Left Behind Act, have linked the improved achievement of students to the overwhelming need for qualified teachers of excellence (Strawn, Fox, & Duck, 2008). According to Haberman (1995), science needs to be relevant to a child's experience for the child to be successful. As a teacher, one must be able to understand the child's specific learning and environmental circumstances and be willing to be flexible to those needs in order to be successful. Successful urban science teachers need to be organized, creative with the lack of resources, and willing to look for help outside of their schools.

In order to maximize the effectiveness of recruitment and retention strategies, it is important to identify factors that contribute to persistence and success in the urban classroom. In this study, persistence is defined as having voluntarily remained in an urban school for 10 years after receiving certification, and success is defined using the definition of Haberman (1993) as teachers who, by all common criteria, are outstandingly successful: Their students score higher on standardized tests, parents and children think they are great, principals rate them highly, other teachers regard them as outstanding, central office supervisors consider them successful, cooperating universities regard them as superior, and they evaluate themselves as outstanding teachers.

Currently, relatively little is known about influential factors in the retention of science teachers of color in the urban setting. In attempting to understand the experience of African-American urban science teachers, it is important to locate their experiences within the theoretical framework of critical race studies that examine how an ideology of race fuels racial stereotypes and discrimination and affects curriculum, pedagogical theory, and educational practice (Tate, 1997). As we take a closer look at the urban public school experience, it is important to note how this history of inequity and oppression has shaped the socioeconomic and pedagogical environment in which teachers, administrators, and students operate. Calmore (1992) posits that our experiences as people of color are legitimate, appropriate, and effective bases for analyzing the legal system and racial subordination and discrimination; in this study the experiences of teachers of color are used in the analysis of success and retention in urban public school science teaching. By legitimizing their voices as the most pertinent, the most relevant, and the authority, we are able to understand how these teachers become agents of change in a system of pedagogical inequities and culturally insensitive curricula while ensuring that all of their students are able to succeed.

Schools, districts, and states have tried various strategies to recruit and retain science teachers and to motivate and support teachers' ongoing professional learning. The purpose of this study was to give voice to five African-American science teachers who have been successful and have persisted in teaching science in the urban setting. The study highlights the commonalities of many of their experiences and gives voice to these experiences in their own words.

The primary goal of the study was to identify factors that contributed to the particular teachers' persistence and success in urban science teaching. The study was guided by the following research questions:

1. From the perspectives of the five successful African-American urban science teachers, what factors contributed to excellence in urban science teaching?

2. From the perspectives of the five successful African-American urban science teachers, what factors impacted their persistence and retention in urban science classrooms?

Answers to these questions will be important to policy makers and science teacher educators held accountable for designing effective science teacher preparation, recruitment, and professional development programs to target, most optimally, teachers in the urban setting.

Methodology

The primary goal of this research was to identify factors that contributed to the teachers' persistence and success in the urban classroom. The researcher maintains a database of all graduates from the program over a period of 15 years. The database is constantly updated to reflect the current status of all

graduates including their current school and contact information. From the names of teachers who continued teaching for 10 or more years, 25 were randomly selected and ranked using Haberman's (1993) criteria:

1. Their students score higher on standardized tests.
2. Parents and children think they are great.
3. Principals rate them highly.
4. Other teachers regard them as outstanding.
5. Central office supervisors consider them successful.
6. Cooperating universities regard them as superior.
7. They evaluate themselves as outstanding teachers.

Information for the ranking was obtained from discussion with supervisors, school officials, and the teachers. The top-ranking 15 teachers were invited to be part of a voluntary focus group; the 5 teachers who participated were available for inclusion in the focus group.

The research design utilized qualitative research using a phenomenological perspective to answer questions about lived or social experiences and to give meaning to these experiences (Patton, 2002). The researcher approaches the research from a phenomenological perspective to shed light on the factors to which these five successful African-American teachers attribute their persistence and success in urban science teaching. Following in their footsteps as they reflect on their journey in urban science teaching can provide insights into areas that need to be addressed in graduate and professional development programs. The phenomenology research strategy was used to examine the experiences of the five African-American science teachers, who, by their performance, were judged to be successful teacher leaders in an urban setting. The phenomenon of the selected teachers' experiences in urban schools was used as a framework to provide insight and understanding into the individual experiences as well as investigate the underlying meaning behind teachers' experiences.

The intent is not to generalize to all African-American science teachers or to all science teachers but rather to provide insights into how the participating teachers experienced urban science teaching and what factors they perceived as significant to their persistence, success, and retention in urban science teaching. It is up to the reader of the study to surmise if the conditions in the study match their own situation and determine whether the findings are transferable or not.

Participants

In this study, the participants were three females and two males.

Carissa migrated to the United States from the Caribbean after completing her undergraduate science degree and teacher training qualifications. She taught in the Caribbean for five years before coming to the United States. She spent 17 years as a high school Advanced Placement Chemistry and Biology teacher. During her seventh year in the school system she entered the master's degree program to obtain her certification to teach science. On completion of her degree, she remained teaching science for two years then became an assistant principal (AP) continuing to teach science. At this point, she enrolled in an administration program and obtained her master's in administration. Seven years after being an AP, she applied and was invited to become principal of a science charter school in her neighborhood. She continues to teach one science class and conduct in-house professional development for her school. In her community she is acknowledged as a science teacher who makes a difference in the lives of her students and gets them to succeed where others have failed.

Delores was born in the United States of West Indian parents and maintained a close link with the West Indian community. Upon completion of her undergraduate degree, she worked as an engineer for four years. Lack of satisfaction with her job led her to a teaching career. She began teaching middle-school Earth science, health, and mathematics. After four years, she moved to the high school where she taught chemistry and Earth science. She moved on to become an AP and eventually a principal. As a principal, she continues to teach chemistry. She has now taught for 16 years. After teaching for six years, she enrolled in a master's program and became involved in curriculum development in her school and district. In her first year of teaching, she was able to move her Earth science scores from 18% passing to 54% and continued to achieve high rates of success in all her classes.

Tamika was born in the West Indies and completed her tertiary education in Cardiff, Wales. After graduating with an honor's degree in chemistry, she returned to Jamaica and began her career in teaching. She taught in a high school and community college for six years before joining her family in the United States. Tamika taught at a high school for 15 years and, based on her performance as an outstanding teacher of

students who were failing in science, she was selected by her district to become a science instructional specialist. She also continues to teach science.

Anthony attended a community college in his neighborhood before going out of state to complete his bachelor's degree. He then taught in two states before returning to his home state. He has taught science in both middle and high school and has been credited with being able to get failing students to achieve, graduate, and move on to top- rate universities. Based on his outstanding classroom management skills and ability to interact with his students he was recently appointed dean of discipline at his school. However, he continues to teach science and has been a science teacher for 26 years.

William was born and raised in the city where he attended public school. After graduating from a Vocational and Technical High School, he attended the local Community College and graduated with an associate's degree in electrical technology. After graduating he worked as a paraprofessional for six years at his old high school. He then went on to complete a bachelor's degree in electro-mechanical engineering technology. As a physics teacher, William's students had a 91.3% passing score on the state exam. Eighty percent of his urban students graduated with honors in 2006. William is in his 27th year of teaching.

The five participants all had an undergraduate degree with a major in one of the sciences. They were all teaching without certification in urban schools, which were described by the state to be low-performing schools currently under restricted review with predominantly minority students from low socioeconomic status. They were selected to participate in a state-funded graduate program in which their tuition was paid for by the grant, and they were required to teach in the urban setting for three years upon graduation. These teachers have now remained in the city for 10 years after graduation. The graduate program focused on providing participants with

- a better understanding of science and scientists;
- a better understanding of how young students learn science;
- appropriate science teaching strategies, resources, and materials; and
- a way to overcome fear or uncertainty about teaching science.

Upon graduation from the program all participants continued a relationship with both faculty and their peers through

1. Mentoring: A master teacher visited classrooms and assisted with curriculum implementation and action research for two years after graduation.
2. Networking: Following their mentoring phase they served as cooperating teachers for preservice teachers, attended monthly support meetings at the university, and presented their classroom-based research to their peers at the annual program conference and at national meetings.
3. Regional Professional Development: They attended and presented workshops conducted in their region.
4. Saturday Science Seminar Series: A free monthly series of seminars focusing on current research topics and recent progress in the fields of biological and biomedical sciences. Teachers meet with the leading scientists working at the frontiers of biological fields.
5. Annual Sharing of Our Success Conference: A forum for urban science and mathematics teachers, school district personnel, and science and mathematics university faculty to meet and share their successful strategies for increasing urban student interest and participation in science and mathematics.

Focus Group Description

Well-structured focus groups become an important tool in gaining access to the strategies used by teacher leaders to create excellence. Through the use of focus groups, we had the chance to look at what professional development strategies have worked and have translated successfully into urban classrooms through the voices of teachers themselves. Focus groups are a way of listening to people and learning from them (Morgan, 1998). Furthermore, it allows researchers a look into what teacher leaders see as important to the making of schools of excellence: what has worked, what has been challenging, and how their teaching and learning have evolved in an urban environment. The focus group is a collectivistic rather than an individualistic research method that focuses on the multivocality of participants' attitudes, experiences, and beliefs (Madriz, 2000). With this knowledge, we may have a better understanding of how to implement effective professional development, how to support teachers, and how to make more successful urban science classrooms.

At the beginning of the first focus group session the researcher framed the discussion by stating

> *We are here to talk about your experiences with science teaching in an urban setting. Many of our*

students come into the program, graduate and teach in the city for two or three years, and then they go to the suburbs. But you have stayed here. I want to know why you have stayed . . . and I also want to know what you do that makes your students successful. What do you do to motivate them? What do you do to make them successful in science? And what have you done that makes you a good science teacher leader? What are your views on urban science teaching and learning? What makes for excellence in urban science teaching? What makes you a successful teacher? What makes a successful urban science classroom?

Following this introduction, the researcher became a participant observer and did not participate in facilitating or guiding the direction of the conversation. This methodology gives more weight to the participants' opinions, decreasing the influence the researcher has over the interview process (Madriz, 2000). It also encourages researchers to listen to the voices of those who have been subjugated and represents a methodology that is consistent with the particularities and everyday experiences of people of color. The conversations were audio-recorded, transcribed by a research assistant, and verified by participants. The following procedure was used to collect the data for the study: First, the focus group session consisted of the teachers discussing the particularities of teaching in an urban environment, their successes, and their failures. Participants met at 10 a.m. and talked until 2 p.m. with a break for snacks, coffee, and lunch. Second, at the end of the session, they were asked to write a Science Teaching and Learning Autobiography explaining how they had become involved in teaching science and why they stayed.

Findings

Factors Contributing to Excellence in Urban Science Teaching

From the perspectives of the five successful African-American urban science teachers in this study, there were five abilities that contributed to their success and excellence in urban science teaching and making their classrooms successful places for student achievement:

1. to understand the learner (Tamika);
2. to have some knowledge of how society and their past school experiences dictate the way students learn (William);
3. to identify students' individual needs and expectations (Carissa);
4. to link learning to individual experience (Delores); and
5. to always implement teaching strategies that are informed by the social and cultural contexts in which students are learning (Carissa).

Their discussions and writing supported the belief that science teachers should create a supportive and challenging environment by

1. fostering effective communication with all students, individually and collectively;
2. allowing equal access to materials/resources within the classroom; and
3. providing experiences that reflect a diversity of opinions, values, and issues.

The emanating discussion among participants and their science autobiographies revealed the following commonalities in their beliefs about science teaching:

1. Students need to be top priority (Tamika).
2. Professional development and staff support is critical (Carissa).
3. Reading and mathematics need to be integrated into science (Anthony).
4. Teaching includes after-school life and social support (Carissa).
5. Schools need community support (Delores).
6. Teachers need to follow students throughout their pre-professional lives. (Tamika)
7. Consistent classroom management is critical (William).
8. Teachers and students need mentoring and positive affirmation (Anthony).

Factors That Impacted Persistence and Retention in Urban Science Classrooms

From the perspectives of the five successful African-American urban science teachers, what factors impacted persistence and retention in urban science classrooms?

Five themes emerged from the focus group discussions as being the critical factors that contributed to their persistence, success, and retention in the urban science classroom.

In-Depth Knowledge and Love of Science

> Tamika: "The love for science just blossoms over and gets the children excited."

Delores: "Excellent science teachers are excited, motivated, they want to do things differently, always participating in workshops, trying to get additional ideas."

Tamika: "That deep love for science is clearly visible to your students to the point that every day when you get up you are truly motivated so that the kids see that."

Carissa: "I look at it as I love what I do and I love seeing when those light bulbs go off. That is my high. When they get it and they are running with it, it motivates me to go further."

The first issue addressed by all participants was the need for in-depth knowledge of the subject they were teaching and the constant search to expand that knowledge. They were all in agreement that you can only teach a subject for which you have an in-depth understanding and continued commitment to advancement in knowledge. They agreed that excellent science teachers also have a deep love for science and convey that love to their students. The love of science motivates excellent teachers to constantly find new ways of conveying science to their students. One participant described the love, understanding, motivation cycle that goes on in a successful science class.

It should be noted that once this area was discussed participants no longer referred to this need. Their main focus turned to issues that concerned the needs of the urban child and how they saw themselves addressing these needs in the science classroom.

Understanding, Caring, and Commitment to the Whole Child

Anthony: "You have to get into the population that you are teaching, and be prepared to address the social issues. This is true especially for urban kids, you must have an understanding of their home situation, it is totally important to their success."

Carissa: "You have to love the students, really love them. Kids are funny people, you know like how they say 'dogs know when you like them, they want to stick with you, and they feel that out in you.' Students are like that . . . they know when you care and will do anything for you."

Delores: "They see that you are sincere; that you want them to succeed, and they do it for you . . . they succeed for you. One of my students graduated from an Ivy League university a couple years ago and she invited me to her graduation. That is the type of relationship I develop with all my children [she referred to her students as her children]. I follow them through jobs, even after they graduate college. I helped this student get an internship at that university, and she did so well that she was admitted and eventually graduated with her master's degree. She came back to the community and is now teaching in a high school."

Carissa: "Students need a support system to help them survive in their day-to-day life. Often the teacher is the one they turn to for that crucial support. They need to know there is somewhere they can go; they feel like it is a second home away from home. That support system needs to be in place."

Tamika: "Recently, I was in a store in the city, and I saw a young woman shopping. She approached me and said, "Do you remember me? You gave me an alarm clock, I still have it. I recalled that she used to come late to my class every morning; nothing that I said or did made her come to my class on time. So I bought her an alarm clock and the next day she was on time. She kept it through college. Those are the kinds of things we need to do to be successful; it goes beyond teaching, and it is taking the whole child and the family into consideration."

Carissa: "Now for me, I have to see the end product. Not just that I teach a class, but where will this child be four or five years? What can I do to get that child to college? I need to get more involved beyond the classroom. I start looking for programs to increase that child's chance in succeeding beyond high school. For example, most summers I send some of my children (students) to do either research or college prep programs. I try to get them exposed. This is critical to our children."

Anthony: "In this setting we really don't know if we are making a difference immediately. It is one of those professions where you have to wait for

years to determine if you have truly been successful."

Urban schools are institutions in which students from different cultural backgrounds have very different experiences within the same classroom. These experiences are mediated and determined by the classroom teacher–student relationships. Participants maintained that effective teaching and learning is predicated on teachers' knowing and caring about students and having an in-depth understanding of the community. Reflections by participants clearly supported the need to develop caring and long-term relationships with their students.

As teachers, we need to be concerned not only with teaching the curriculum but also with catering to the needs of the whole child. Often what students need to succeed is some small attention to detail as described by this participant—all it took to make this student a success in science was a clock.

These participants focused not only on teaching the child for the current year but also on teaching the child for a lifetime. They saw their role as contributing to the future life of each child in their classroom.

High Expectations and Motivation of Their Students

Anthony: They come into my class, defeated, deflated—left back, once in elementary school, once in junior high school, and now 2 years later, they are still in the eighth grade. So they are a little bit older, a little bit bigger, and a little more beat up intellectually and emotionally than the rest of the students in the other eighth-grade classes.

Anthony, who has a low-level eighth-grade science class, described his students on the first day of class:

Most of the kids that they put together, and bundle up as bad, are not bad. All they want is love and attention. They want to understand and be understood. . . . If you give them some attention and focus, you can help direct some of that negative energy.

Carissa: "Most students responded positively to high expectations and motivation and once they show that potential, I do everything in my power to get kids through that college door. As they enter my class I say to them, 'You are in my science class this year. I expect each one of you to pass your exams. If you do your assignments in and out of class, come to class on time, participate in class and let me know if you do not understand any of the topics we cover in class, you will pass the finals.' "

Delores: "As the year progresses, when my weaker students do well, e.g., submit homework assignments on time, pass an exam, I congratulate them in front of the entire class. Sometimes if they show some marked improvement and I have the funds, I treat them to pizza."

All participants highlighted the need to motivate all their students and to always expect the best of each child who walked through their doors regardless of the "baggage" they brought with them. Tamika uses a unique strategy to motivate her students to complete their assignments. She has discovered that they enjoy discussing random facts in science that affect their daily lives, e.g., that cola once contained cocaine. She will give them a new fact every time the entire class completes an assignment. In this way every class member is motivated to complete assignments because no one wants to be responsible for the class not getting the new random fact.

Effective Classroom Management Strategies and Role Models

William: "They have few models for effective behavior in or outside of a classroom. You need to tell them their own attributes, what will make them successful. They gravitate towards consistency and structure. We tend to not give them that, and the parents are not around. We need to be their role models."

One of the major problems confronted by urban science teachers is the lack of appropriate role models. Many of the children do not have relatives or close acquaintances who can model the appropriate skills needed to succeed in science. Often they do not know how to begin to develop these skills. They have no landmark by which to judge success. In order to successfully teach science, these teachers have all developed their unique teaching and classroom management styles that include the following:

1. Delineating their expectations of these students from day 1. The common expectations include
   a. You are going to pass this course.
   b. You will come to class each day.

c. You will learn in this class and will not prevent others from learning.

d. In this class you are scientists and you act accordingly.

2. Providing consistent discipline and structure to each class. This classroom management style has worked well for these participating science teachers.

Acceptance of the Varying Parental Involvement in the Educational Decisions About Their Children

Tamika: "An excellent teacher needs to be a compassionate person, especially in an urban setting, because the kids have so many issues that if you are not compassionate, you will not be very successful because sometimes you are the only adult that that child can talk to."

Carissa: "Because to be honest, parents may mean well, but they do not understand the system, or how to get their children involved. I tend to call parents and sit down with them and try to direct them."

Urban teachers need to develop strategies that will help them achieve in spite of the limitations of parental involvement. Participants reported having to cope with parents who became parents before they completed high school, who came from cultures where they were not expected to attend high school and hence had no understanding of their required roles in the school system. They were unable to advocate for their children and were often so overwhelmed with the need to work to keep the family from being homeless that they left schooling to the school. In this situation, because of their involvement with the community as residents, as participants in the churches, and the social life of the community, they are aware of the culture and ethos of the community and are better able to relate to the problems that students bring into the classroom from their homes. They are also better able to understand and communicate with parents and guardians.

Summary

What then makes an urban science teacher of excellence? What do schools need to do to ensure that urban teachers are successful in their mathematics and science classrooms? All of the participants saw teaching as a profession that was all encompassing, where students and their lives became a top priority. Furthermore, they were all aware that the culture of their students demanded them to be a teacher, a mentor, a friend, and a parent to their students. More often than not, the teachers pointed out bad behavior, and lack of achievement spoke to things going on outside the classroom rather than a student's capabilities. Students in their classrooms tended to be below grade level and brought issues to the classroom that would not have happened perhaps in another teaching environment. As one teacher pointed out, she had to "*teach vocabulary, so that her students could even understand the questions on the state final exam*" (Delores). Thus, these teachers, whose success rates were overwhelming within the schools in which they worked, had to be aware of the particular needs of their students and have wide-ranging strategies that addressed these needs. They all agreed that urban science education is a most challenging profession but it is also the most rewarding. Emerging themes for their achieving excellence in urban science education included

1. knowing and caring for the whole child;
2. knowing and loving your subject;
3. effective classroom management;
4. expectation and motivation; and
5. understanding the varying limitations of parental involvement

Implications for Science Teacher Education

In developing teacher training programs that can support preservice teachers and professional development workshops for in-service teachers, firsthand knowledge of what it takes to succeed in an urban environment is crucial. This study provides us with some specific traits these successful African-American urban science teachers possess and strategies that they have used within their classrooms to enhance achievement and student growth. These findings can help inform our understanding of the urban teaching environment and the strategies used for increasing student achievement in this population. In their selection processes, science teacher education programs need to consider characteristics of teachers who excel in poor urban schools. This study showed that these characteristics include strong content knowledge, ability to treat urban students with respect, and understanding that teaching is not a job that begins when students walk into the classroom and ends when they leave. Urban science teachers have to be intimately involved in the lives of each child in their class.

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Mathematics Teachers' Instructional Practices in an Era of High-Stakes Testing

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This study explored mathematics teachers' instructional practices in the context of high-stakes testing. Data were obtained from a survey instrument given to a stratified sample of Mississippi and Tennessee teachers who teach the same content tested on their state's high school graduation examination. An analysis showed teachers using a balance of standards-based and traditional practices and tools, including textbook-based assignments, calculators, open-response questions, supplementary materials, and multiple-choice questions. Over 90% of teachers from both states felt that an "interest in helping my students attain test scores that will allow them to graduate high school" was a factor influencing their instructional practices. This was followed by an "interest in helping my school improve high school graduation examination scores," and "belief these are the best instructional practices."

As recently as 25 years ago, educational accountability was considered a local matter. Teachers were responsible to their administrators and local school boards. Local school boards, in turn, set the curriculum as well as the priorities, otherwise known as standards, for their school system. Today, educational accountability has become a state and national concern, as well as a mantra of public education. Teachers, as well as administrators, are being held accountable to the public for the academic performance of students in their charge. States have created curriculum frameworks and mandated testing systems that include high stakes attached to results in order to ensure high standards and accountability.

Just as control of educational issues has shifted between local and state control, public and political control in mathematics education has vacillated between mathematicians and mathematics educators. This struggle, also termed "the math wars" (Latterell, 2005; Schoenfeld, 2004), has included both sides using poor student standardized test results as fodder for their issues. However, neither side has been in control of the mathematics curriculum long enough to truly study the effects of their positions. This is evident in the statements concerning the lack of quality long-term research in the area of mathematics education by the National Mathematics Advisory Panel (2008).

In 1989, the National Council of Teachers of Mathematics (NCTM) released the *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989). This provided standards and a common statement of belief about mathematics education for teachers. While some (Milgram, 2004; Wu, 1996) argue that this document represents the voice of teachers and mathematics educators more than mathematicians, it provides one of the longest sustaining movements for a specific vision in mathematics education. However, this movement does not align with the content found within most exit examinations due to the focus on reasoning, communication, connections between content, and problem solving. Most standardized test questions focus on isolated skills and basic recall and procedural application, rather than the conceptual understanding promoted by the NCTM (1989) standards. Therefore, teachers are faced with a dilemma concerning what information to teach and how to teach it to address the standards and at the same time prepare students for these high-stakes tests.

In this era of standards and educational accountability, teachers have become acutely aware of consequences such as public reporting of test results, prevention of grade-to-grade promotion, and possible school takeover attached to student test results. The pressure to produce at least adequate student high-stakes test results, although felt in varying degrees by all teachers, may be the greatest for those teaching the content tested on their state's end-of-course exit examination, more commonly referred to as a high school graduation examination. On the one hand, these teachers want to use instructional practices that make their classes interesting, develop students' higher-level thinking skills, and spark an interest in the subject and why it is relevant. On the other hand, these teachers have a responsibility to prepare students for the state accountability examination.

The type of graduation examinations used varies among states. Some states require general exit examinations, which test content taught in more than one course. However, other states, such as Mississippi and Tennessee, require end-of-course exit examinations. Unlike general exit examinations, which test content taught in more than one course, end-of-course exit examinations test content taught in just one course and yet passing this examination is required for graduation (Center on Educational Policy, 2005). Students may begin taking a specific exit examination after completing the specified course and may continue taking this examination multiple times each year until they eventually pass and become eligible for graduation. Teachers teaching these "tested" courses have the sole responsibility to prepare students for the high school graduation examination in their content area. Failure to do so may lead to severe consequences being inflicted on their students, their school, and on them (Smith, 1991).

As policymakers continue to authorize the use of statewide examinations to assure that educators (e.g., administrators and teachers) are being held accountable for the education of students in their care, the impact of these examinations on teachers' instructional practices is a very relevant concern, with, as of yet, no clear consensus as to what the impact is. Although researchers such as Barksdale-Ladd and Thomas (2000), Firestone, Schorr, and Monfils (2004), Jones and Johnson (2002), McNeil (2000), Vogler (2002), and Yarbrough (1999) have found that teachers changed their instructional practices in response to state accountability examinations, there is still no clear understanding about the nature and intensity of this relationship (Firestone et al., 2002; Grant, 2001, 2003). Factors such as subject and grade level taught, personal beliefs, type of high-stakes assessment, and professional development all have the potential to impact this relationship in varying degrees (Cimbricz, 2002; Jones, Jones, & Hargrove, 2003).

Statement of Purpose

The purpose of this study was to explore mathematics teachers' instructional practices in the context of high-stakes testing. More specifically, the instructional practices used and factors influencing their use by Mississippi and Tennessee mathematics teachers who teach the same content tested on their state's high-stakes high school graduation examination were compared. As described above, the high school graduation examinations in both Mississippi and Tennessee are end-of-course examinations, which assess whether students have mastered the content of a specific course, Algebra I, at the high school level. These are different than general standards-based exit examinations, which are aligned with state standards and test content taught in more than one course. Information from this study will assist policymakers and educators in assessing the impact this type of high school graduation examination program has had on mathematics teachers' instructional practices.

Central question:

> In what manner does an end-of-course exit examination influence instructional practices?

Additional questions include the following:

1. What instructional practices do teachers use?
2. How often do teachers use these instructional practices?
3. What factors have influenced their use?
4. Are there differences in the instructional practices used and factors influencing their use between teachers from different states? If so, what are they?

Method

A survey instrument (see the Appendix) was used to answer the research questions. This survey instrument was anonymous and was not tied to student achievement in order to receive accurate, uncensored responses from teachers.

Two approaches were used to ascertain the validity and reliability of the instrument. First, evidence was sought for the content validity of the 54 items on the initial draft of the survey instrument. Because this study is part of a larger study about the impact of state-mandated examinations on English, science, mathematics, and social studies teachers' instructional practices, 36 high school teachers (nine English, nine science, nine mathematics, and nine social studies) reviewed the items on the survey instrument for clarity and completeness in coverage the instructional practices used and possible influences. Using their recommendations, the number of items on the survey instrument was reduced to 48.

Second, 34 different high school teachers (nine English, seven science, nine mathematics, and nine social studies) completed the revised 48-item survey instrument. These same 34 teachers completed the revised survey instrument again following a

three-week interval. Reliability was assessed by comparing each teacher's responses. A Pearson's product–moment correlation coefficient was used as the test–retest reliability measure. The correlation coefficient was .82, indicating a high positive relationship and well above the .70 needed to ensure the reliability of the survey instrument (McMillan & Schumacher, 2001). Sixty-four percent of the teachers had exact matches for all items; 88% of the matches were within one point on the six-point scale, and 92% of the matches were within one point on the five-point scale.

Sample Selection

A stratified sample of Mississippi and Tennessee high school mathematics teachers was created using the variables geographic region, past student success on the state accountability examination, and numbers of high school Algebra I teachers in the school system. First, school systems were grouped according to each state's geographic regions: east, middle, and west. Second, the school systems in each region were ranked according to student success on the latest state accountability examination—the Subject Area Testing Program in Mississippi and Gateway in Tennessee. Quartiles were generated using this ranking. At least four, but no more than six, school systems from each quartile participated in the study. Third, because the first two steps in the sampling procedure focused on selecting school systems and not teachers, the school systems selected in each region were chosen in part because they included similar numbers of high school Algebra I mathematics teachers from large and small school districts. This prevented teachers in large school districts or from less sparsely populated areas from being overrepresented in the sample. The end-of-course mathematics examination in both states is based solely on content from Algebra I. This could be due to the research that supports the critical nature of algebra as a predictor for future success, such as those expressed by the National Mathematics Advisory Panel (2008).

In Mississippi, 64 school systems were asked and a total of 55 school systems agreed to participate in the study. All high school mathematics teachers teaching Algebra I from each participating school system were given a cover letter and the survey instrument by their principals or school designate. The cover letter explained the nature and certain aspects of the study—for example, how to calculate instructional time spent on test preparation. Teachers were told to count days in which they taught test-taking mechanics such as filling in bubbles and test pacing methods, used commercial test preparation materials, and gave practice tests with items similar to those on the state accountability examination as instructional time spent on test preparation. One hundred and twenty (120) teachers, or 64.2% of the total sample, completed the survey instrument.

In Tennessee, 65 school systems were asked and a total of 53 school systems agreed to participate in the study. All high school mathematics teachers teaching Algebra I from each participating school system were given a cover letter and the survey instrument by their principals or school designate. The cover letter and survey instrument were the same as those given to the Mississippi teachers. One hundred and seventy-three (173) teachers, or 67% of the total sample, completed the survey instrument.

It should be noted both Mississippi and Tennessee offer the end-of-course mathematics examination three times a year, and students may take the test as many times as needed in order to earn a passing score for graduation. Also, advanced students in these states may take Algebra I as early as seventh grade, and are therefore eligible for taking the end-of-course exit examination upon completion of the course. However, the voices on this survey represent only those who teach Algebra I in high school. This is because these teachers are most likely to feel the impact of the end-of-course exit examination for graduation rather than their middle school colleagues and have the greatest likelihood of the examination impacting instruction.

Comparison of Survey Sample and State Teaching Population

Characteristics of the Mississippi and Tennessee survey respondents were compared with those of each state's teaching population using data obtained from Part III of the survey instrument and the Mississippi and Tennessee Departments of Education. Table 1 is a comparison of the frequency distribution between the Mississippi and Tennessee survey response sample and the Mississippi and Tennessee high school Algebra I teacher population for gender, education, and teaching experience.

With a few slight exceptions, Table 1 shows that participants in this study are representative of the Mississippi and Tennessee high school Algebra I teaching population in terms of gender and education, and the Mississippi high school Algebra I teaching population in terms of teaching experience. (The Tennessee Department of Education had no information regarding teaching experience.)

Table 1
Comparison of Sample and Mississippi and Tennessee High School Algebra I Teacher Population for Gender, Education, and Teaching Experience

Demographic variable	High School Algebra I Teacher Population							
	Mississippi				Tennessee			
	Sample		State		Sample		State	
	%	*n*	%	*n*	%	*n*	%	*n*
Gender								
Female	75.8	91	75.4	524	67.6	117	66.3	334
Male	24.2	29	24.6	171	32.4	56	33.7	170
Education								
Bachelor's	62.5	75	65.3	454	44.5	77	38.7	195
Master's	37.5	45	32.2	224	51.4	89	53.8	271
Specialist's	00.0	00	1.9	13	2.4	4	5.5	28
Doctoral	00.0	00	.6	4	1.7	3	2.0	10
Teaching experience (years)								
0–6	34.2	41	36.0	250	22.6	39	No info available	
7–14	30.0	36	26.0	181	29.4	51	No info available	
15–24	23.3	28	22.2	154	28.4	49	No info available	
25+	12.5	15	15.8	110	19.6	34	No info available	

Results

Before we begin, it is important to define the terms standards-based instruction and traditional instruction. Standards-based instruction is aligned with the NCTM principles that were created with a large influence from the mathematics education community (Latterell, 2005; Schoenfeld, 2004). This type of instruction can be thought of as devoting more time to problem solving, reasoning, communicating thinking in order to construct personal meaningful understandings of mathematical concepts (Baxter, Woodward, & Olson, 2001; Brooks & Brooks, 1993; Jones et al., 2003).

Traditional instruction places the teacher at the center of all activities (Jones et al., 2003). Typically, this method of instruction includes a preponderance of practices such as lecture, lecture and discussion, direct instruction, and the use of assessments focusing on lower-level knowledge (e.g., multiple-choice questions) (Brooks & Brooks, 1993; Eggen & Kauchak, 2001; Jones et al.).

Although distinguishing practices as either standards-based or traditional is an inexact division (mostly dependent on teachers' curricular intention), still, the contrasting methods provide a general framework from which to analyze and compare teachers' instruction. To be sure of this framework, a principal component analysis was conducted on the instructional practices and tools listed in the survey instrument. The results of this analysis are shown in Table 2.

Components with eigenvalues greater than 1.0 were retained and rotated with a varimax rotation. The analysis revealed that two factors accounted for 68% of the variance. These factors were labeled "standards-based instruction" (19 items) and "traditional instruction" (eight items). One item, role playing, loaded on both factors (using .30 as the cutoff point). However, the second loading was lower than the first one (see Table 2). The values of alpha for the two subscales were a satisfactory .86 and .79, respectively.

Table 2
Factor Analysis

Item	Standards-Based Instruction	Traditional Instruction
Project-based assignments	.77	
Inquiry/investigation	.73	
Coop learning/group work	.71	
Charts/webs/outlines	.68	
Group projects	.68	
Open-response questions	.65	
Interdisciplinary instruction	.63	
Visual aids	.58	
Computers/Internet	.57	
Computers/educational software	.56	
Calculators	.55	
Problem-solving activities	.52	
Creative/critical thinking	.50	
Newspapers/magazines	.48	
Role playing	.46	.33
Discussion groups	.45	
Supplementary materials	.42	
Audiovisual materials	.39	
Lessons on current events	.36	
True–false questions		.73
Worksheets		.66
Multiple-choice questions		.65
Lecturing		.63
Textbooks		.58
Textbook-based assignments		.52
Rubrics or scoring guides		.49
Modeling		.42
Eigenvalue	4.0	2.2
% of variance explained	39.7	28.3
Alpha	.86	.79

Table 3
Comparison of Mississippi and Tennessee High School Algebra I Teachers' Regularly and Mostly Used Instructional Practice or Tool

Instructional Practice or Tool	Mississippi Total % Regularly and Mostly Used	Tennessee Total % Regularly and Mostly Used	Significance	Effect
Textbook-based assignments	93.3	89.6	.269	.06
Textbooks	93.3	89.0	.209	.07
Calculators	88.3	93.6	.110	.09
Lecturing	80.0	83.2	.479	.04
Supplementary materials	73.3	83.8	.029*	.12
Problem-solving activities	65.8	70.5	.395	.04
Modeling	63.3	76.3	.016*	.14
Open-response questions	57.1	62.9	.321	.05
Worksheets	56.7	66.5	.088	.09
Multiple-choice questions	55.5	39.3	.006**	.15
Visual aids	53.3	60.7	.298	.09
Coop learning/ group work	53.3	45.1	.165	.08

* $p < .05$; ** $p < .01$.

Balance of Standards-Based and Traditional Practices and Tools

Part I of the survey instrument was designed to answer the study's first two guiding questions and part of the fourth guiding question. Table 3 compares the practices Mississippi and Tennessee survey respondents reported using regularly or mostly. Instructional practices or tools used regularly and often means respondents either circled "4" for RU (regularly) or "5" for M (mostly) on Part I of the survey instrument. Instructional practices or tools used less often or not at all means respondents either circled "1" for D (don't use), "2" for R (rarely), or "3" for O (occasionally) on Part I of the survey instrument. It also notes statistically significant differences between respondents from the two states.

An analysis of Table 3 shows that survey respondents from both states are using a balance of standards-based and traditional practices and tools. For example, of the first six instructional practices or tools respondents reported using the most, three are of a traditional nature and three can be considered instruction more in line with a standards-based approach. As stated above, these practices do not necessarily indicate that standards-based instruction or traditional instruction is occurring, because we do not know the teachers' intentions. However, it does give an idea as to the type of activities occurring and could be used to support future qualitative exploration in this area. In fact, of the 12 instructional practices or tools respondents reported using the most, six are standards-based practices and six can be considered instruction more in line with a traditional approach. Table 3 also shows there is a statistically significant difference in the use of three practices (supplementary materials, modeling, and multiple-choice questions) between the respondents from Mississippi and Tennessee, but the effect size shows this is a weak relationship.

Table 4 compares the practices Mississippi and Tennessee respondents reported using instructional practices or tools less often or not at all.

Whereas Table 3 shows respondents using a balance of standards-based and traditional practices, an analysis of the practices respondents reported using less often or not at all presents a slightly different picture.

Table 4
Comparison of Mississippi and Tennessee High School Algebra I Teachers' Occasionally, Rarely, and Not Used Instructional Practice or Tool

Instructional Practice or Tool	Mississippi Total % Occasionally, Rarely, or Not Used	Tennessee Total % Occasionally, Rarely, or Not Used
Role playing	97.3	98.7
Newspapers/magazines	94.9	92.3
Project-based assignments	91.7	89.5
Current events	89.7	91.4
Computers/Internet	88.1	80.0
True–false questions	82.4	91.3
Group projects	81.7	87.8
Writing assignments	79.0	84.6
Interdisciplinary instruction	76.1	78.5
Computers/educational software	75.6	68.2
Inquiry/investigation	64.7	69.6
Creative/critical thinking question	64.2	52.9
Audiovisual materials	63.3	62.4
Discussion groups	58.8	73.1
Charts/webs/outlines	55.8	55.8
Rubrics or scoring guides	52.9	82.5

Table 4 shows respondents in both states report spending the least amount of instructional time using standards-based instructional practices and tools such as role playing, newspapers/magazines, project-based assignments, computers/internet, group projects, writing assignments, interdisciplinary instruction, inquiry/investigation, and creative/critical thinking questions. Many of these are strongly advocated by the NCTM (2000). In fact, of the 16 instructional practices and tools respondents acknowledge using occasionally, rarely, and not at all, only two, true–false questions and rubrics or scoring guides, can be considered instruction more in line with a traditional learning approach.

Lack of a Significant Relationship Between Instructional Practices and Time Spent on Test Preparation

Questions #31 and #32 in the survey instrument ask about preparing students for the accountability examination (see the Appendix). Ninety-five respondents, or 70.8% of the total response sample of Mississippi teachers, and 152 respondents, or 87.8% of the total response sample of Tennessee teachers acknowledged spending instructional time preparing students for the high school graduation examination. But, rather than just dividing respondents into two groups, those that did and did not prepare students for the examination, comparisons were also made based on the amount of instructional time spent preparing students for the examination. The preparation time category was "collapsed" into "zero days," "one day to two months," and "over two months" in order to ensure cell numbers sufficient to meet minimum requirements for a chi-square analysis. Cross-tabulations and chi-square analyses were conducted to determine if there were any significant differences between the instructional practices used or not used and the "collapsed" preparation time categories. A larger sample size is

Table 5
Comparison of Regularly and Mostly Used Instructional Practice or Tool by State and Respondents' Instructional Time Spent Preparing Students for Exam

Instructional Practice or Tool	Total % Regularly and Mostly Used					
	Mississippi			Tennessee		
	Time Spent Preparing Students for Exam					
	None*	1 Day–2 Months†	Over 2 Months‡	None§	1 Day–2 Months¶	Over 2 Months**
Textbooks	96.0	100.0	89.2	100.0	87.7	87.4
Textbook-based assignments	92.0	96.7	92.3	100.0	89.2	87.4
Lecturing	84.0	83.3	76.9	85.7	90.8	77.0
Multiple-choice questions	76.0	26.7	60.9	23.8	35.4	46.0
Problem-solving activities	52.0	63.3	72.3	61.9	72.3	71.3
Calculators	48.0	96.7	100.0	95.2	89.2	96.6
Open-response questions	48.0	63.3	57.8	30.0	67.7	67.1
Modeling	32.0	56.7	60.0	38.1	43.1	48.3
Supplementary materials	44.0	70.0	86.2	81.0	84.6	83.9
Worksheets	44.0	50.0	64.6	57.1	64.6	70.1
Coop learning/group work	32.0	56.7	60.0	38.1	43.1	48.3
Visual aids	28.0	46.7	66.2	66.7	56.9	62.1

* $n = 25$; † $n = 30$; ‡ $n = 65$; § $n = 21$; ¶ $n = 65$; ** $n = 87$.

suggested for future studies to clarify the middle category. Table 5 is a comparison of the instructional practices and tools regularly and mostly used by the Mississippi and Tennessee respondents spending zero days, one day to two months, and over two months of instructional time preparing students for the high school graduation examination.

An inspection of Table 5 reveals that generally, there is a minimal relationship between instructional practices used most often by Mississippi and Tennessee respondents and the amount of time spent on test preparation. The most noticeable comparison is that teachers from both states spending time preparing students for the end-of-course examination are more likely to use standards-based practices such as problem-solving activities, open-response questions, and supplementary materials than those spending no time preparing students for the examination. And teachers from both states spending the most time preparing students for the high school exit examination are more likely to use standards-based practices such as calculators and cooperative learning/group work as well as the traditional practices such as modeling and worksheets than those spending one day to two months and no time preparing students for the examination.

But Table 5 also shows a number of differences between the instructional practices used most often by respondents of both states and the amount of time spent on test preparation. For instance, in Mississippi, the traditional practices of textbooks and textbook-based assignments are being used most often by respondents spending one day to two months preparing students for the examination; but in Tennessee, they are being used by 100% of the teachers spending no time preparing students for the examination. And lecturing and multiple-choice questions are being used most often by Mississippi respondents spending no time preparing students for the examination, but in Tennessee, lecturing is being used most often by respondents spending one day to two months

Table 6
Comparison of Influence Factors

Item	Mississippi Total % Agree and Strongly Agree	Tennessee Total % Agree and Strongly Agree	Significance	Effect
37. Interest in helping my students attain test scores that will allow them to graduate high school	99.2	91.3	.004**	.16
36. Interest in helping my school improve high school graduation exam scores	93.3	85.0	.028*	.12
33. Personal desire	89.2	85.0	.299	.06
34. Belief these are the best instructional practices	81.7	88.4	.108	.09
41. Interactions with colleagues	80.8	69.4	.028*	.12
35. Format of the exam	77.5	60.7	.003**	.17
42. Staff development in which I have participated	64.2	67.1	.608	.02
38. Interest in avoiding sanctions at my school	54.2	38.7	.009**	.15
40. Interaction with school principal(s)	46.7	37.0	.098*	.09
43. Interactions with parents	39.2	34.1	.375	.05
39. Interest in obtaining a monetary award for my school	15.8	17.9	.641	.02

* $p < .05$; ** $p < .01$.

preparing students for the examination and multiple-choice questions are being used by teachers spending the most time preparing students for the high school exit examination.

The Powerful Influence of Testing on Instruction

Part II of the survey instrument was designed to answer the study's third guiding question and part of the fourth guiding question—influence factors. Table 6 compares the factors influencing the instructional practices and tools Mississippi and Tennessee respondents report using. It also notes statistically significant differences between respondents from the two states.

An examination of Table 6 reveals that over 90% of teachers from both states felt that an "interest in helping my students attain test scores that will allow them to graduate high school" was a factor influencing their use of instructional practices. And for respondents from both states, this factor was followed by an "interest in helping my school improve high school graduation examination scores," "personal desire," and "belief these are the best instructional practices." Also, less than half of the respondents from both states felt that "interactions with school principal(s)," "interactions with parents," and "interest in obtaining a monetary award for my school" were factors influencing their instructional practices.

Finally, Table 7 is a comparison of the influence factors by the Mississippi and Tennessee respondents spending zero days, one day to two months, and over two months of instructional time preparing students for the accountability examination.

In Table 7, we see the impact high school exit examination scores have had on teachers' instructional practices. Over 90% of respondents from both states spending time preparing students for the high school

Table 7
Comparison of Influence Factors by State and Respondents' Instructional Time Spent Preparing Students for Exam

Item	Total % Regularly and Mostly Used					
	Mississippi			Tennessee		
	Time Spent Preparing Students for Exam					
	None*	1 Day–2 Months†	Over 2 Months‡	None§	1 Day–2 Months¶	Over 2 Months**
37. Interest in helping my students attain test scores that will allow them to graduate high school	100.0	100.0	98.5	74.2	91.2	96.6
36. Interest in helping my school improve high school graduation exam scores	84.0	100.0	93.8	42.9	90.8	90.8
33. Personal desire	84.0	96.7	87.7	81.0	81.5	88.5
41. Interactions with colleagues	80.0	80.0	81.5	76.2	72.3	65.5
42. Staff development in which I have participated	76.0	56.7	63.1	66.7	66.2	67.8
34. Belief these are the best instructional practices	56.0	96.7	84.6	90.5	90.6	86.2
38. Interest in avoiding sanctions at my school	44.0	43.3	63.1	33.3	36.9	41.4
40. Interactions with school principal(s)	53.3	70.8	62.0	31.4	40.0	46.8
35. Format of the exam	32.0	96.7	86.2	38.1	53.8	71.3
43. Interactions with parents	20.0	50.0	41.5	33.5	33.8	34.5
39. Interest in obtaining a monetary award for my school	16.0	13.3	16.9	23.8	20.0	14.9

* $n = 25$; † $n = 30$; ‡ $n = 65$; § $n = 21$; ¶ $n = 65$; ** $n = 87$.

graduation examination said that an "interest in helping my students attain test scores that will allow them to graduate high school" and "interest in helping my school improve high school graduation examination scores" were factors influencing their instructional practices. And in Mississippi, examination scores seem to be important regardless of the time spent preparing for the examination—100% of the Mississippi respondents spending no time preparing students for the examination said an "interest in helping my students attain test scores that will allow them to graduate high school" and 84% said "interest in helping my school improve high school graduation examination scores" were factors influencing their instructional practices.

Discussion

The purpose of this study was to explore mathematics teachers' instructional practices in the context of high-stakes testing. An analysis of the data show three interesting themes: (1) a balance of standards-based and traditional practices and tools; (2) a lack of a significant relationship between the type of instructional practice used and time spent on test preparation;

and (3) the influence of high-stakes testing on instruction.

Teachers in both states are more likely to use a balance of standards-based and traditional practices, which some say is the most effective way to teach (Airasian & Walsh, 1997; Pressley, Rankin, & Yokoi, 1996; Zemelman, Daniels, & Hyde, 1998). Standards-based methods are more effective for teaching complex objectives and developing higher-level thinking skills, and traditional methods are more effective for teaching procedural skills and organizing knowledge to review facts and identify relationships (Good & Brophy, 2000).

Although it is impossible to describe the perfect balance between standards-based and traditional instruction due to factors such as subject, grade level, and lesson objectives (Jones et al., 2003), research on best practices (Daniels & Bizar, 1998; Wenglinsky, 2000; Zemelman et al., 1998) and position papers of professional teaching organizations (e.g., NCTM) have advocated instructional practices more connected to standards-based methods. So, while educators recognize that both traditional and standards-based approaches are effective for student learning, only standards-based approaches are seen as instruction that allow students to connect new ideas to their previous knowledge and experience, to think critically and creatively, and thereby develop higher-level thinking skills. Traditional approaches, by contrast, are seen as instruction only useful for developing lower-level thinking skills such as identifying, memorizing, and listing information.

According to the data, teachers from both states are using instructional practices and tools such as calculators, textbook-based assignments, supplementary materials, lecturing, problem-solving activities, worksheets, modeling, and multiple-choice questions. In other words, these respondents are using a balance of standards-based and traditional instructional practices. However, the amount of time and focus spent on both is what is unclear. As stated earlier, these practices tend to lend themselves to either traditional or standards-based instruction, but the reality of practice lies within the intention of the teacher. Are teachers providing enough standards-based instructional practices to empower students to make sense of mathematics in personally meaningful ways and to utilize higher-order thinking strategies to solve mathematical problems?

Data also indicate that the results of the high school exit examination are important for both Mississippi and Tennessee Algebra I teachers. Over 70.8% of Mississippi teachers and 87.8% of Tennessee teachers acknowledged spending class time preparing students for the high school exit examination; and of those teachers, 68.4% of the Mississippi teachers and 57.2% of the Tennessee teachers spent over two months preparing students for the examination. Comparisons were made among teachers in both states spending no time, one day to two months, and over two months preparing their students for the high school exit examination. The results of these comparisons lead to the second theme—the lack of a relationship between the type of instructional practice used and time spent on test preparation.

According to the data, teachers from both states, regardless of the amount of instructional time spent preparing students for the high school exit examination, are mostly using a combination of standards-based and traditional approaches. There was no notable distinction found between the teachers' instructional practices used and the amount of time spent preparing student for the graduation examination. Presumably, these teachers feel that using a balance of standards-based and traditional instructional approaches is not only the best way to teach, but it is the best way to prepare their students for the high school graduation examination.

A look at each state's assessment system shows aspects of both standards-based and traditional instructional philosophies, but a majority of the focus is aligned with traditional content and instructional practices. For example, while portions of the Mississippi and Tennessee Algebra I end-of-course examination mirror standards-based beliefs such as items containing charts, graphs, or diagrams for students to use, the use of strictly multiple-choice questions in concert with each state's rather traditional mathematics course sequence send mixed messages about the type of instruction that is valued (see Mississippi State Department of Education, 2007; Tennessee Department of Education, 2008).

This leads to the issue of teachers' instructional decisions, and the last theme—the powerful influence of testing on instruction. Comparisons among respondents from both states reporting zero days, one day to two months, and over two months preparing students for the high school graduation examination and the factors influencing the instructional practices they use yielded interesting results. For each of these groups of respondents (with the exception of Tennessee teachers

spending no time preparing students for the high school exit examination), the top two reasons, or influence, for the instructional practices they use were the same: an "interest in helping my students attain test scores that will allow them to graduate high school" and an "interest in helping my school improve high school graduation examination scores."

Limitations

There are some limitations to this study that must be noted. First, a survey instrument can only measure self-reports of past actions. Respondents to this survey may have been mistaken in the amount of time spent using instructional practices; they may have under-reported or over-reported the use of certain instructional practices compared with what actually occurred in the classroom. The survey was anonymous and was not tied to student achievement in order to encourage teachers to be frank and honest about their practices without concern for their own reputation.

Second, this study's survey instrument only provided teachers with a list of instructional practices and influence factors. There may be other instructional practices mathematics teachers are using and factors influencing their use that were not included in the survey instrument. Third, the survey only asked what instructional practices teachers are using, not how they are using them. Potentially, there may be a difference. For example, two teachers say they regularly use role playing in their classroom. One teacher uses prepared scripts. The other teacher allows students to decide on the characters and situation as a group and then write a script. The first teacher is clearly using role playing as more of a traditional practice, whereas the second teacher is using it as more of a standards-based practice. The second teacher empowers the students to problem-solve and create meaning using role playing as the venue for learning. Therefore, the practice listed on the survey does not assure that it is used in an instructional practice that is necessarily traditional or standards based. Finally, the data used in this study was collected from a self-administered survey instrument. Because of the study's nonexperimental design, it is not appropriate to draw definitive conclusions about causality from this study.

Recommendations

One recommendation would be for policymakers, and those who have a stake in the education of tomorrow's population, to begin to think more broadly about accountability to ensure that students are not harmed by tests that were meant to ensure quality education. As this study shows, most teachers want to see their students succeed, regardless of external incentives. This suggests that collaborative policymakers could then find ways to work with teachers to enhance education in less harmful ways.

Another recommendation would be for administrators and teacher educators to provide opportunities for high school mathematics teachers to gain valuable standards-based pedagogy to facilitate students' critical thinking skills. By becoming more comfortable with this type of pedagogy, teachers may find that regardless of test format, students are thinking at much higher levels and are more prepared for life after high school.

Finally, this study offers many insights that could be explored in greater depth in future studies. For example, qualitative studies of these instructional practices in courses with high-stakes exit examinations could shed light on how each practice is used. Correlating practices with student achievement could provide support for which practices support higher achievement. Also, interviewing teachers about their instructional practices and the impact of end-of-course exit examinations would provide greater depth to this larger, quantitative study.

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Appendix: The Survey Instrument

Part I

Please circle the number indicating the extent to which you use each of the following:

Use the following scale:

D = Don't Use
R = Rarely (Average less than 1 day per week)
O = Occasionally (Average 1 day per week)
RU = Regularly (Average 2 to 4 days per week)
M = Mostly (Average 4 to 5 days per week)
NA = Not Applicable (not used in your high school academic program)

Instructional Strategies

	D	R	O	RU	M	NA
1.Writing assignments	1	2	3	4	5	6
2. Group projects	1	2	3	4	5	6
3. Textbook based assignments	1	2	3	4	5	6
4. Discussion groups	1	2	3	4	5	6
5. Multiple-choice questions	1	2	3	4	5	6
6. Open-response questions	1	2	3	4	5	6
7. True-false questions	1	2	3	4	5	6
8. Inquiry/Investigation	1	2	3	4	5	6
9. Problem-solving activities	1	2	3	4	5	6
10. Worksheets	1	2	3	4	5	6
11. Lessons based on current events	1	2	3	4	5	6
12. Project-based assignments	1	2	3	4	5	6
13. Creative/critical thinking questions	1	2	3	4	5	6
14. Role playing	1	2	3	4	5	6
15. Use of charts, webs and/or outlines	1	2	3	4	5	6
16. Use of response journals	1	2	3	4	5	6
17. Use of rubrics or scoring guides	1	2	3	4	5	6

Teaching Techniques

	D	R	O	RU	M	NA
18. Interdisciplinary instruction	1	2	3	4	5	6
19. Lecturing	1	2	3	4	5	6
20. Modeling	1	2	3	4	5	6
21. Cooperative learning/ group work	1	2	3	4	5	6

Instructional Materials and Tools

	D	R	O	RU	M	NA
22. Textbooks	1	2	3	4	5	6
23. Supplementary materials	1	2	3	4	5	6
24. Newspaper/ magazines	1	2	3	4	5	6
25. Audiovisual materials	1	2	3	4	5	6
26. Lab Equipment	1	2	3	4	5	6
27. Calculators	1	2	3	4	5	6
28. Computers/ educational software	1	2	3	4	5	6
29. Computers/ internet and/or on-line research service	1	2	3	4	5	6
30. Visual aids (i.e., posters, graphs)	1	2	3	4	5	6

31. Do you prepare students for the high school graduation examination?

___ Yes (Please answer question 32.)

___ No (Please skip questions 32. Go to question 33.)

32. Preparation Time (Amount of instructional time you spend preparing students for the high school graduation exam.)

___No more than 1 day
___2-3 days
___1 week
___2-3 weeks
___1 month
___2-3 months
___4-6 months
___Over 6 months

Part II

Please circle the number indicating your responses to the statements below, using the following scale:

SD = Strongly Disagree
D = Disagree
U = Undecided
A = Agree
SA = Strongly Agree

The instructional practices I use have been influenced by the following:

	SD	D	U	A	SA
33. Personal desire	1	2	3	4	5
34. Belief these are the best instructional practices	1	2	3	4	5
35. Format of the high school graduation examination	1	2	3	4	5
36. Interest in helping my school improve high school graduation examination scores	1	2	3	4	5
37. Interest in helping my students attain test scores that will allow them to graduate high school	1	2	3	4	5
38. Interest in avoiding sanctions at my school	1	2	3	4	5
39. Interest in obtaining a monetary award for my school	1	2	3	4	5
40. Interactions with school principal(s)	1	2	3	4	5
41. Interactions with colleagues	1	2	3	4	5
42. Staff development in which I have participated	1	2	3	4	5
43. Interactions with parents	1	2	3	4	5

Part III

Please mark the responses that describe you.

44. ___Male ___Female

45. Teaching Experience

___First year
___2-6 years
___7-9 years
___10-14 years
___15-19 years
___20-24 years
___25-29 years
___30 years or more

46. Education (Highest level attained)

___Bachelor's Degree
___Master's
___Master's +15
___Master's +30
___Master's +45
___Master's +60
___C.A.G.S. or Specialist's
___Doctorate

47. Teaching Assignment (Primary teaching assignment)

___English
___Mathematics
___Science
___Social Studies

48. State (State you teach in)

___Mississippi
___Tennessee

THANK YOU VERY MUCH FOR YOUR TIME

Comments regarding instructional practices you use to prepare students for the high school graduation examination:

The NCTM Process Standards and the Five *Es* of Science: Connecting Math and Science

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This study investigates defining characteristics among the process standards of the Principles and Standards for School Mathematics and the 5 Es *from the National Science Education Standards and the Inquiry and the National Science Education Standards. These characteristics are used to demonstrate similarities and differences between the learning of mathematics and science, discuss implications from such, and argue for the integration of mathematics and science curriculum and instruction.*

For decades, practitioners and educators of mathematics and science have argued for the integration of mathematics and science in K-12 instruction. Some of the organizations promoting this integration include School Science and Mathematics Association, National Council of Teachers of Mathematics (NCTM), American Association for the Advancement of Science, and the National Research Council (NRC). Furner and Kumar (2007) posit a number of arguments for this instructional integration, including that the segregation of mathematics and science instruction allows for few connections to be recognized between the two fields and for few real-world applications to be investigated. When mathematics and science learning is segregated, the context of the investigated phenomenon is lost and students are less able to solve real-life problems (Frykholm & Glasson, 2005). "Science provides mathematics with interesting problems to investigate, and mathematics provides science with powerful tools to use in analyzing them" (Rutherford & Ahlgren, 1990, pp. 16–17).

Research demonstrates that integrated curricula provide endless opportunities for more relevant, less fragmented, and more stimulating experiences for learners (Frykholm & Glasson, 2005; Jacobs, 1989; Koirala & Bowman, 2003) and advocates cite that curriculum integration helps students form deeper understandings, see the "big picture," recognize relevance to life, make connections among central concepts, and become interested and motivated in school (Berlin, 1994; George, 1996; Mason, 1996). Integration of content areas can help students learn to think critically and help develop a common core of knowledge necessary for success in the next century (Carnegie Council on Adolescent Development, 1989).

Constructivists contend that students learn through connections formed between prior knowledge and new experiences and as connections arise among existing ideas. This notion is accentuated by brain research that supports thematic teaching (Cohen, 1995) and the idea that all people process information in a more comprehensible way through patterns and connections than fragmented pieces (Beane, 1996). Some educators contend that student motivation and attitudes become more positive when students experience integrated curricula (Friend, 1985; Wolfe, 1990) and that this positive motivation leads to increases in student achievement in both subjects (McBride & Silverman, 1991).

This article proposes a novel argument for the integration of mathematics and science instruction. Distinct from arguments stating that the natures of mathematics and science are complementary and together form a more powerful problem-solving tool, that mathematics and science are best learned interconnectedly, and that integrated curricula enhance student motivation, this investigation leads to the argument in support of the integration of mathematics and science learning based on the understanding that both subjects are learned in the same way. This will be developed through the investigation of learning processes associated with both subject matter areas.

Background for the Research and Findings

The investigation of the respective learning processes in mathematics and science cannot be performed in isolation of a number of additional factors that have been found to affect learning. Herein we define the learning processes of mathematics and

science and consider social and affective issues regarding learning.

Mathematics and Science Learning Processes

The NCTM *Principles and Standards for School Mathematics* (2000) clearly defines five process standards for the learning of mathematics. These processes function as simultaneous goals for student learning, activities, habits, and processes through which mathematical content is learned. Thus, for instance, while it may be a goal for teachers to get students communicating mathematics to one another, the process of communicating also *leads* to the learning of mathematics. The NCTM process standards are clearly defined and encapsulated in the following five areas: *Problem Solving*, *Reasoning and Proof*, *Communication*, *Connections*, and *Representations*. Providing characteristics of each of these process standards, NCTM (2000) states:

> Instructional programs from prekindergarten through grade 12 should enable all students to: build new mathematical knowledge through ***problem solving***; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems; monitor and reflect on the process of mathematical problem solving . . . . Problem solving means engaging in a task for which the solution method is not known in advance. In order to find a solution, students must draw on their knowledge, and through this process, they will often develop new mathematical understandings. . . . Students should have frequent opportunities to formulate, grapple with, and solve complex problems that require a significant amount of effort and should then be encouraged to reflect on their thinking. (p. 52)

> Instructional programs from prekindergarten through grade 12 should enable all students to recognize ***reasoning and proof*** as fundamental aspects of mathematics; make and investigate mathematical conjectures; develop and evaluate mathematical arguments and proofs; select and use various types of reasoning and methods of proof. . . . Mathematical reasoning and proof offer powerful ways of developing and expressing insights about a wide range of phenomena. People who reason and think analytically tend to note patterns, structure, or regularities in both real-world situations and symbolic objects; they ask if those patterns are accidental or if they occur for a reason; and they conjecture and prove. Ultimately, a mathematical proof is a formal way of expressing particular kinds of reasoning and justification. . . .
>
> By developing ideas, exploring phenomena, justifying results, and using mathematical conjectures . . . , students should see and expect that mathematics makes sense. . . . By the end of secondary school, students should be able to understand and produce mathematical proofs—arguments consisting of logically rigorous deductions of conclusions from hypotheses—and should appreciate the value of such arguments. (p. 56)

> Instructional programs from prekindergarten through grade 12 should enable all students to: organize and consolidate their mathematical thinking through ***communication***; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; use the language of mathematics to express mathematical ideas precisely. . . . Communication . . . is a way of sharing ideas and clarifying understanding. Through communication, ideas become objects of reflection, refinement, discussion, and amendment. The communication process also helps build meaning and permanence for ideas and makes them public. When students are challenged to think and reason about mathematics and to communicate the results of their thinking to others orally or in writing, they learn to be clear and convincing. Listening to others' explanations gives students opportunities to develop their own understandings. Conversations in which mathematical ideas are explored from multiple perspectives help the participants sharpen their thinking and make connections. (p. 60)

> Instructional programs from prekindergarten through grade 12 should enable all students to: recognize and use ***connections*** among mathematical ideas; understand how mathematical ideas interconnect and build on one another to produce a coherent whole; recognize and apply

mathematics in contexts outside of mathematics. . . . When students can connect mathematical ideas, their understanding is deeper and more lasting. They can see mathematical connections in the rich interplay among mathematical topics, in contexts that relate mathematics to other subjects, and in their own interests and experience. Through instruction that emphasizes the interrelatedness of mathematical ideas, students not only learn mathematics, they also learn about the utility of mathematics. (p. 60)

Instructional programs from prekindergarten through grade 12 should enable all students to: create and use ***representations*** to organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena. . . . When students gain access to mathematical representations and the ideas they represent, they have a set of tools that significantly expand their capacity to think mathematically.

The term *representation* refers both to process and to product—in other words, to the act of capturing a mathematical concept or relationship in some form and to the form itself. . . . Moreover, the term applies to processes and products that are observable externally as well as to those that occur "internally," in the minds of people doing mathematics. All these meanings of representation are important to consider in school mathematics. . . .

Representations should be treated as essential elements in supporting students' understanding of mathematical concepts and relationships; in communicating mathematical approaches, arguments, and understandings to one's self and to others; in recognizing connections among related mathematical concepts; and in applying mathematics to realistic problem situations through modeling. (p. 67)

For more extensive treatments of some of these process standards, Yackel and Hanna (2003) investigate the role of *Reasoning and Proof* and Lampert and Cobb (2003) consider the aspect of *Communication* in mathematics learning. Notably, since *Representations* is the newest of the process standards and has been added since the publication of the *Curriculum and Evaluation Standards* (NCTM, 1989), significant work has been published in respect to this standard (e.g., Goldin, 2003; Monk, 2003; Smith, 2003)

The NRC's two publications, *National Science Education Standards* (NRC, 1995) and *Inquiry and the National Science Education Standards* (NRC, 2000), do not specifically contain clearly defined process standards as such. Rather, these science documents employ a sequence of 5 *Es*, through which science lessons should progress. These 5 *Es* include the following five areas: *Engagement*, *Exploration*, *Explanation*, *Elaboration* or *Extension*, and *Evaluation*. These standards, although not directly equivalent to the five process standards of mathematics education, have strikingly similar characteristics as process standards; they can be recognized both as instructional stages and processes through which students learn science. The *Inquiry and the National Science Education Standards* (NRC, 2000) delineates the phases of instruction through which the 5 *Es* are experienced:

> Phase 1: Students **engage** with a scientific question, event, or phenomenon. This connects with what they already know, creates dissonance with their own ideas, and/or motivates them to learn more. (p. 35) . . . Scientifically oriented questions center on objects, organisms, and events in the natural world. . . . They are questions that lend themselves to empirical investigation, and lead to gathering and using data to develop explanations for scientific phenomena.
>
> In the classroom, a question robust and fruitful enough to drive an inquiry generates a "need to know" in students, stimulating additional questions of "how" and "why" a phenomenon occurs. . . . Fruitful inquiries evolve from questions that are meaningful and relevant to students, but they also must be able to be answered by students' observations and scientific knowledge they obtain from reliable sources. (p. 24–25)

> Phase 2: Students **explore** ideas through hands-on experiences, formulate and test hypotheses, solve problems, and create explanations for what they observe. (p.35) . . . In their classroom inquiries, students use evidence to develop explanations for scientific phenomena. (p. 26)

Phase 3: Students analyze and interpret data, synthesize their ideas, build models, and clarify concepts and **explanations** with teachers and other sources of scientific knowledge. (p. 35) . . . Explanations are ways to learn about what is unfamiliar by relating what is observed to what is already known. So, explanations go beyond current knowledge and propose some new understanding. . . . For students, this means building new ideas upon current understandings. (p. 26–27)

Phase 4: [*Elaboration*] Students **extend** their new understanding and abilities and apply what they have learned to new situations. (p. 35) . . . Alternative explanations may be reviewed as students engage in dialogues, compare results, or check their results with those proposed by the teacher or instructional materials. An essential component of this characteristic is ensuring that students make the connection between their results and scientific knowledge appropriate to their level of development. (p. 27)

Phase 5: [*Evaluation*] Students, with their teachers, review and **assess** what they have learned and how they have learned it. (p. 35) . . . Having students share their explanations provides others the opportunity to ask questions, examine evidence, identify faulty reasoning, point out statements that go beyond the evidence, and suggest alternative explanations for the same observations. Sharing explanations can bring into question or fortify the connections students have made among the evidence, existing scientific knowledge, and their proposed explanations. As a result, students can resolve contradictions and solidify an empirically based argument. (p. 27)

Bass, Contant, and Carin (2009) and Magnusson and Palincsar (2005) provide additional historic and more extensive descriptors and examinations of the 5 *Es*.

To simplify the vocabulary in this discussion, both the process standards from mathematics and the 5 *Es* from science will herein be denoted ***learning processes***. Therefore, recognizing learning processes in the fields of both mathematics and science learning, the question naturally arises regarding the similarities and differences between the NCTM process standards and the 5 *Es* of the *National Science Education Standards*.

Sequential Linearity Among Learning Processes

Predating and providing a foundation upon which the 5 *Es* were constructed was the three-phase learning cycle developed through the Science Curriculum Improvement Study (SCIS) at the University of California, Berkeley, through the late 1950s and early 1960s (Bass et al., 2009; Lawson, Abraham & Renner, 1989). These three phases included *Exploration*, *Concept Investigation*, and *Concept Application*. Notably, this learning cycle was, for the most part, sequential—with more sequential flexibility allowed for formal operational learners and less sequential flexibility allowed for concrete operational learners (Abraham & Renner, 1983, 1986; Renner, Abraham, & Birnie, 1983, 1985a, 1985b). Renner and his colleagues reinforced the notion that the learning cycle is most effective when used as originally designed and observed that all three phases of the model must be included in instruction, and the exploration phase must precede the term introduction phase; the specific instructional format may be less important than including all phases of the model, but lab work (typical exploration phase) is more effective for many students, provided it is followed by discussion (term introduction); and student attitudes toward science instruction are more positive when they are allowed to explore concepts through experimentation or other activities before discussing them.

Although little research explicitly states that the 5 *Es* are sequential, their founding upon the SCIS Learning Cycle strongly argues that linearity is their intent. That is, within the science education standards documents (NRC, 1995, 2000) and countless other science education publications, *Engagement*, *Exploration*, *Explanation*, *Elaboration* (or *Extension*), and *Evaluation* are almost universally demonstrated as sequential, and this research has discovered no publication that explicitly defines the 5 *Es* as nonlinear. Indeed, the strongest argument for the assumed linearity of the 5 *Es* may be based on the fact that they are delineated as sequential *phases* in the *Inquiry and the National Science Education Standards* (NRC, 2000). Rarely are any of the 5 *Es* mentioned in strict isolation of the role they play with the *E* that precedes and follows them.

Conversely, the mathematics process standards are never treated as sequential. While the *Principles and Standards* (NCTM, 2000) does not explicitly state that the process standards are nonlinear, throughout the document and countless other mathematics education

documents, the process standards are repeatedly considered both independently and as completely and continuously intertwined with no sequence associated with such. Many publications consider one or more process standards with limited interrelation to other process standards. This research has discovered no publication that either tacitly or explicitly states that the NCTM process standards are either sequential or nonlinear. Nevertheless, through the totality of the discussions around the process standards, nonlinearity can be assumed.

Social and Affective Dimensions of Learning. Learning is a social process (Vygotsky, 1978, 1986) primarily found in the interaction within groups (Swan & Shea, 2005). A sense of community forms, knowledge is constructed, and learning occurs as a result of communication and interaction within a group (Brown et al., 1993; Cazden, 1988; Cobb, 1994; Wenger, 1998; Wertsch, 1985). Bielaczyc and Collins (1999) believe that, in order for community to be formed and maintained within a group, all members must both participate fully and be accepted by all others.

In education generally and in mathematics and science education specifically (Alsop & Watts, 2003; McLeod, 1988, 1989, 1990, 1994; Perrier & Nsengiyumva, 2003), researchers have for decades considered the role of emotions in learning. These discussions typically fall under the realms of attitude (McLeod, 1992; Osborne, Simon, & Collins, 1993) and motivation (Glynn & Koballa, 2006; Glynn, Taasoobshirazi, & Brickman, 2007; Mazlo et al., 2002; Schiefele & Csikszentmihalyi, 1995; Simpson, Koballa, Oliver, & Crawley, 1994). Altogether, research has demonstrated that students learn mathematics and science more effectively when they have positive ideas toward such and have positive motivations to learn.

Research Methodology

The preliminary research questions addressed in this study include:

1. To what extent are the NCTM process standards similar to and different from the 5 *Es* of the *National Science Education Standards*? and
2. If learning processes from mathematics and science demonstrate conceptual commonalities, are these commonalities sufficient to imply that students learn both mathematics and science through similar processes?

Simultaneously considering literature from different fields of study (mathematics education and science education) holds inherent difficulties. The two fields often employ similar vocabulary with a far different meaning attached to such. Conversely, the two fields of study typically use different vocabularies that hold the same meaning. Thus, it is often necessary to go beyond the prose within each field to ascertain more salient and foundational characteristics and then compare/contrast those characteristics. This later process often requires either the recasting of concepts and vernacular in one field to those in another or the invention of entirely new verbal descriptors.

In order to assess commonalities and distinctive traits among these learning processes in the two fields, a mathematics educator and a science educator were paired together to work in a series of investigatory phases. In the first phase, each educator independently investigated the learning processes of their respective field. They were assigned to use only the standards documents of their separate content area (i.e., *Principles and Standards for School Mathematics* (NCTM, 2000), *National Science Education Standards* (NRC, 1995), and *Inquiry and the National Science Education Standards* (NRC, 2000)) in order to determine the most salient characteristics of their respective learning processes. The results of each educator's investigation were kept private and not shared with the other. In the second phase, the same subject matter experts in science and math education reversed the review process and each independently investigated the learning processes in the standards documents of the other's field. These results were again kept private. In the third phase, the two original content specialists met with another professional educator and the three reviewed all the results and developed a mediated comprehensive list of characteristics for each learning process.

Altogether, the research methodology employed herein is a modified form of check-coding (Miles & Huberman, 1994), where each of the researchers independently coded the same items of data. It was the intent of the panel that this process of using content experts, initiating the investigation independently (to avoid ideational contamination), and then joining findings (with the assistance of an additional educator to act as a mediator who would carefully balance the discussions and results) would provide more reliability and validity to the results of the investigation. Notably, a number of additional phases of this research

methodology occurred after these three initial phases; these additional phases are defined in the following sections.

Delimitations

A number of significant delimitations affect this investigation:

1. The number of content experts (mathematics and science) was constrained to one from each area and a mediator. It was decided that while additional researchers may have strengthened the research, the descriptive nature of this project would have led to overly complex and extensive descriptors that would have become unwieldy and would produce negligible gains.

2. Although additional resources regarding these learning processes could have been investigated, after preliminary investigation it was determined that many of the seminal resources regarding such were already used by the writers of the respective standards documents and that most post hoc commentaries on these learning processes were redundant to the standards and added few descriptive characteristics and insights to these learning processes. More importantly, it was decided to look singularly at the respective standards documents since most teachers and curriculum developers are more familiar with, and make almost exclusive use of, these standards documents rather than other resources when investigating curricular issues.

Continuing Investigation, Findings and Discussions

The following sections take an unusual form. Typical research reports delineate findings prior to proffering discussions regarding such. Herein, the development of the research methodology and the subsequent unearthing of additional findings make reporting findings and simultaneously discussing such more coherent.

As is the case with some qualitative research methodologies, research questions lead to findings that lead to additional questions, and in turn lead to more findings. This was the case with this investigation. Thus, the following findings are discussed in order of their discovery.

Seminal Concepts within Learning Processes

In the first phase of the study, the researchers independently investigated the learning processes found in their respective standards. This resulted in dozens of sentence-length descriptions (which were too lengthy to be included herein). In the second phase, the researchers independently investigated the learning processes found in respective standards of the opposite field. This again resulted in dozens of sentence-length descriptions. In the third phase, the two content area experts and the mediator joined to accomplish the following. First, redundant descriptive sentences were eliminated. Second, the content area specialists collaborated in the rewriting of the remaining sentences. Then sentences were codified and abbreviated to descriptors limited to only a few words in length. A total of 51 seminal descriptors was found. Notably, the following descriptors are cryptic and provide only a purposefully terse summary of a descriptive characteristic.

NCTM Process Standards

Problem Solving: Task Engagement; Connection to Prior Knowledge; Extend and Solidify Knowledge; Disequilibrium; Exploration, Risk Taking, and Communication

Reasoning and Proof: Justifying and Defending; Systematic Exploration; Hypothesizing and Investigating; Peer-Mediated Development

Communication: Multimodal; Making Connections; Justifying Solutions; Formal and Informal; Foster Engagement and Ownership; Misconceptions Mediated; Reasoning; Reflection

Connections: Viewed Holistically; Conceptual and Procedural; Relationships; Internal and External; Extending to New Ideas

Representations: Model Making; Select/Apply/Translate; Connection; Problem Solving

5 Es of Science Education

Engagement: Disequilibrium; Predicting; Making Connections Between Past and Present Learning Experiences; Organize Student Thinking; Generating Curiosity

Exploration: Movement Toward Equilibrium; Test and Refine Predictions and Hypotheses; Communication; Mediated Investigation; Common Experiences; Patterns and Relationships

Explanation: Formal and Informal; Synthesize Ideas; Model Making; Clarify Concepts; Formalizing Language; Demonstrating Conceptual Understanding; Multimodal

Elaboration/Extension: Extend/Apply Understanding; Check Peers' Understanding; Present and Defend Explanations; Draw Reasonable Conclusions; Formalizing Language

Evaluation: Students Receive Feedback; Lead to Future Investigations; Reflection/Self-Examination; Able to Answer Open-Ended Questions; Evidence of Development of Change in Thinking/Behavior

Connections among the Learning Processes

Following the discovery of these characteristic descriptors of the mathematics and science learning processes, the researchers returned to the standards documents and ensured that the descriptors adequately represented the respective learning processes in the context of the documents. Upon further analysis, numerous common notions were discovered among these conceptual descriptors and some of these descriptors were determined to be sufficiently synonymous to justify collapsing the list to fewer descriptors. For instance Task Engagement (*Problem Solving*) and Generating Curiosity (*Engagement*) were consolidated and Model Making was found in both *Representations* and *Explanation*. Consolidating synonymous descriptors led to the total number of descriptors to be reduced from 51 to 24, including: Exploration, Risk Taking, and Communication; Foster Engagement and Ownership; Viewed Holistically; Select/Apply/Translate Connect Among; Solve Problems; Task Engagement and Generating Curiosity; Disequilibrium; Predicting, Hypothesizing, Investigating; Systematic Exploration/Mediated Investigation/Organize Student Thinking; Making Connection Between Past and Present Learning Experiences; Peer-Mediated Development; Multimodal; Formal and Informal Language and Communication; Justify and Defend Solutions, Reasoning, Synthesize Ideas; Demonstrating Conceptual and Procedural Understanding; Use Internal and External Connections and Relationships and Solidify Understanding; Apply Understanding and Extend Knowledge to New Ideas and Future Investigations; Model Making; Reflection/Self-Examination; Movement Toward Equilibrium; Patterns and Relationships; Students Receive Feedback; Able to Answer Open-Ended Questions; and Evidence of Development of Thinking/Behavior.

Through the use of diagrammatic software as an investigative tool, descriptors were then backward mapped to the learning processes from which they originated and to which they were applicable. This process resulted in the creation of Figure 1.

Of the 51 initial descriptors used for all 10 learning processes, only 10 (20%) were sufficiently distinct so to disallow collapsing with some other descriptors. The fact that out of 51 descriptors 41 (80%) were shared among learning processes in both subject areas demonstrated to the investigators that a strong conceptual correlation existed between the mathematics and science learning processes. Through additional searching for synonymous vocabulary and contextual meanings, adequate correlation was found among 41 of the initial descriptors, allowing this list to be collapsed into 24 conjoined descriptors. This further indicated that strong correlation existed between the learning processes in each field. *Summarily, this conceptual correlation implied to the investigators that to a great extent mathematics and science are learned in similar ways and through similar processes.*

The mapping of descriptors to learning processes (in Figure 1) revealed that no learning processes were independent of others in the same field. For instance, the NCTM process standard *Communication* shared common traits with each of the other NCTM process standards. Thus, no single math or science learning process stood in isolation. The interconnections found among mathematics and science learning processes demonstrated that no one mathematical learning process equated completely with any one science learning process. Rather, descriptors were often seen associated with numerous learning processes. Thus, no pair of learning processes (one from math and another from science) was found to be synonymous.

From each area of study, five descriptors were recognized as sufficiently disjoint in meaning to disallow uniting with any other descriptors. This implied that while the math and science learning processes were united on 41 (80%) out of 51 descriptors, they were significantly different on 10 descriptors to demonstrate that mathematical thinking and learning may differ from science thinking and learning as defined by these descriptors. While this investigation does not further analyze these 10 descriptors for additional implications, it is adequately apparent that the learning of mathematics is not precisely equivalent to the learning of science. Thus, it is sensible to realize that, although the training and preparation of teachers in mathematics and science can be quite similar, some attention should be paid to the differences between these two fields in the respective training.

One of the more unique differences between the learning processes of mathematics and science discovered in this analysis lies in a dimension within the science learning processes that speaks to the changing of a learner's beliefs and practices. While mathematics educators certainly wish for students to learn to think mathematically, science educators wish for the learning of science to change the thinking and behavior of students. Students in science are to frame both habits of mind and practice. For instance, studying

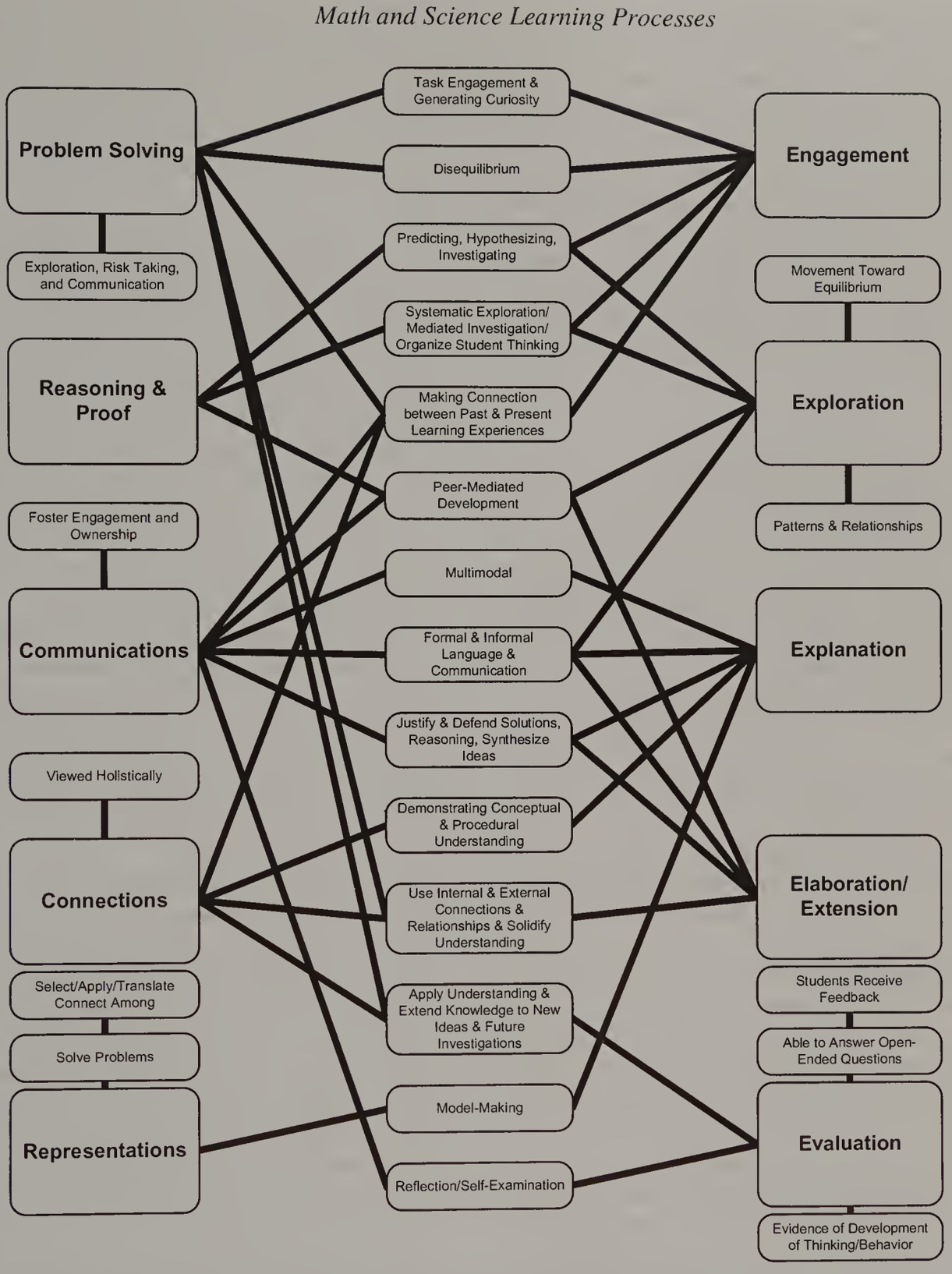

Figure 1. Connections among learning processes from mathematics and science education based on discovered characteristics among them.

ecology should lead a student to be more ecologically minded and take on personal practices that are consistent with what has been learned in this arena. This notion of wishing the study of the subject matter to transform and better the student's beliefs and practices are not lost in the *Principles and Standards for School Mathematics* (NCTM, 2000); rather these notions are more in line with the set of principles included in these mathematics standards and not in the process standards (learning processes).

Notably, the initial research questions proposed in this study have now been answered: Process standards of the *Principles and Standards for School Mathematics* (NCTM, 2000) and the 5 *Es* from the *National Science Education Standards* (NRC, 1995) and the *Inquiry and the National Science Education Standards* (NRC, 2000) have been found to closely correlate and this correlation is sufficient to imply that students learn both mathematics and science through similar processes. The remainder of this report discusses a number of additional findings resulting from this investigation that go beyond the initially intended questions.

Unanticipated Findings

Further analysis of Figure 1 led to a number of unanticipated findings that transcend the initial research questions and warrant the reporting and discussion of such. These unanticipated findings are in the realms of the social and affective dimensions to learning and the sequential linearity and nonlinearity of the learning processes.

Social and Affective Dimensions to Learning

Figure 1 provides insights into how people learn mathematics and science through social interaction. Numerous descriptors evolved from the previous analyses that indicate the necessity of communal learning. These descriptors include: Exploration, Risk Taking, and Communication; Systematic Exploration and Mediated Investigation; Peer-Mediated Development; Formal and Informal, Multimodal Language and Communication; Justify and Defend Solutions and Reasoning and Synthesize Ideas; and Students Receive Feedback. Altogether, these numerous descriptors lead to the understanding that effective learning of mathematics and science involves a social dimension and that learning is not usually accomplished independently and in isolation.

Learning involves the sharing of ideas among a group of people, the mediating of ideas and understanding, and the communicative interaction and participation of all. To encourage students to understand why their rules apply to many cases, the teacher must create a classroom environment in which "students learn to expect and ask for justifications and explanations from one another" (NCTM, 1991, p. 58). Justification occurs in both the science and mathematics classroom. Students defend their initial hypotheses and conclusions concerning the problem or task at hand with other members of their group, their teacher, and with themselves, in self-reflection and discussion following input from others. This socially constructed knowledge that the students gain should be likened to the fundamental role played by communication and social interaction in the development of science and mathematical ideas through history.

Another dimension that can be recognized among some of the descriptors in Figure 1 is the interaction of the person's psyche and emotions during the learning of mathematics and science. The descriptors leading to this affective dimension are: Task Engagement and Generating Curiosity; Disequilibrium; Risk Taking; Movement Toward Equilibrium; Foster Engagement and Ownership; and Reflection and Self-Examination. These descriptors paint the picture that emotions play a central role in learning and that the classroom environment serves to support or hinder the learner's ability to positively relate to learning.

Sequential Linearity and Non-Linearity

Having previously discovered that the science learning processes correlated to the mathematics learning processes on 41 of 51 characteristics, this argues that the two groups of learning processes are conceptually interconnected. However, this may be logically inconsistent if the learning processes of mathematics and science differ so significantly on a defining characteristic as critical as linearity.

The correlation between linear and nonlinear learning processes immediately raises two significant implications. First, the 5 *Es* of science education may not be as sequential as they usually appear and are treated. Because the science learning processes are tightly correlated to the math learning processes, the latter of which are recognized as nonsequential, it is logically contrary that the 5 *Es* can be completely linear and sequential. The correlation with the math learning standards implies that science learners move in and among the 5 *Es*, as needed, as they progress through learning experiences. While this movement can be mostly sequential, cognitive dissonance and disequilibrium experienced in the problem investigation process may make the learner take a step back, leap ahead, make conjectures out of sequence, or go back to the beginning and reevaluate presuppositions and supposed prior knowledge. Second, the NCTM process standards may be more sequential than they usually appear and are treated. Because the mathematics learning processes were correlated to the mostly sequential science learning processes, it is illogical

Math and Science Learning Processes

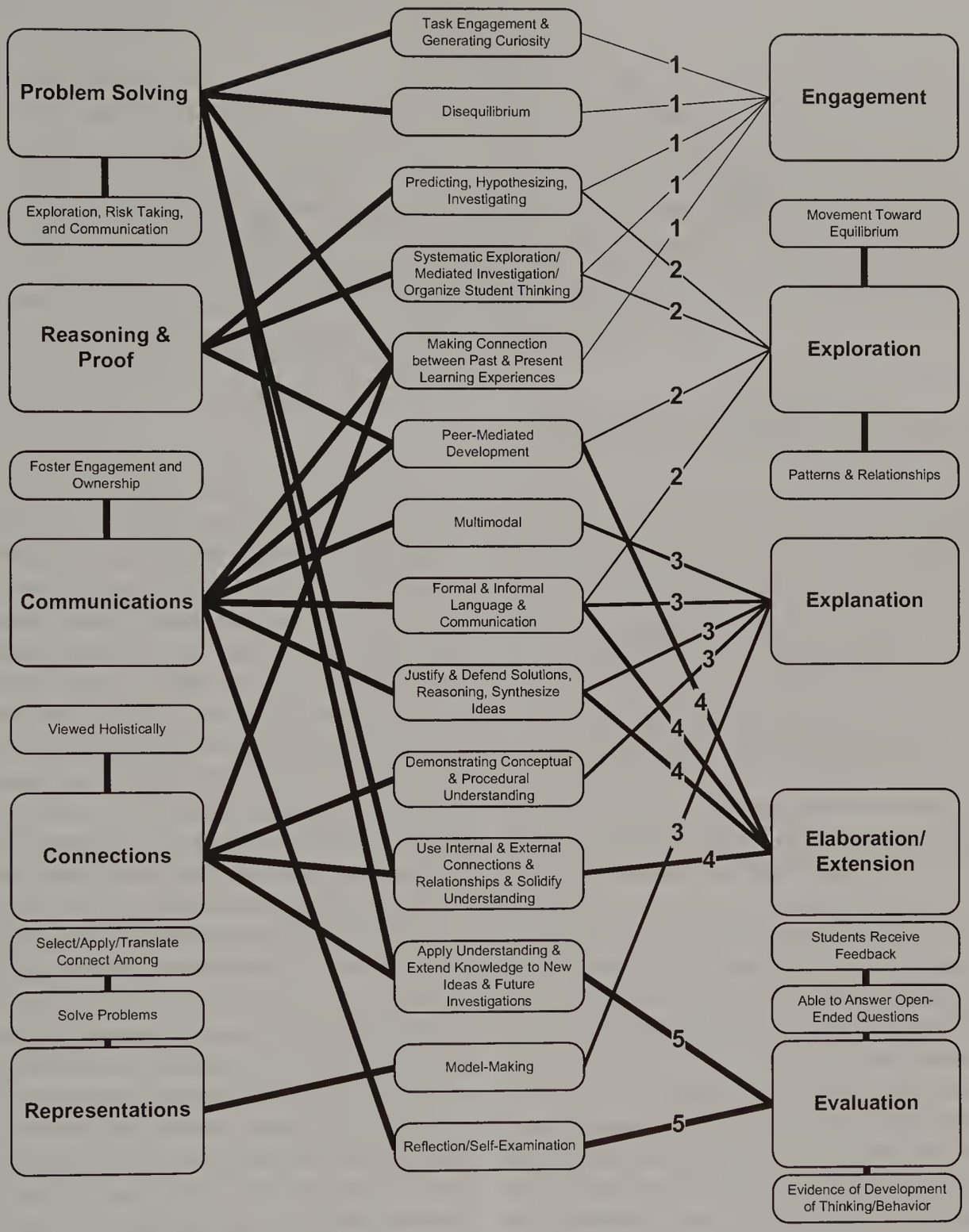

Figure 2. Weighted links investigating the linearity of the mathematics learning processes.

that some semblance of sequencing does not naturally occur as a learner experiences mathematics.

To assess the possible linearity of the mathematics learning processes, a weighted scale was ascribed to the 5 *E*s: *Engagement* = 1, *Exploration* = 2, *Explanation* = 3, *Elaboration* = 4, and *Evaluation* = 5. These weighted links were applied to Figure 1 and resulted in the formation of Figure 2.

For each descriptor to which a mathematical learning process connected, the weight and number of the

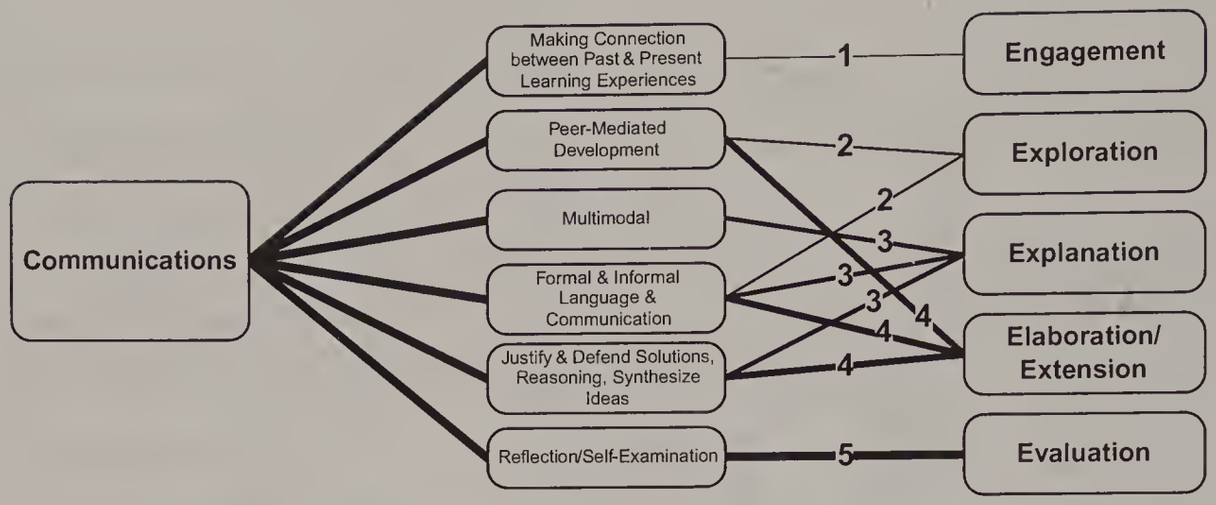

Figure 3. Example of results of weighted links.

links from the science learning processes were tabulated. This created a ratio from which the average weighted linking could be determined:

$$\text{Score} = \frac{\begin{array}{c}\text{sum of weighted links reaching}\\ \text{characteristics associated with}\\ \text{a learning process}\end{array}}{\begin{array}{c}\text{number of links reaching characteristics}\\ \text{associated with a learning process}\end{array}}.$$

Figure 3 denotes a subset of Figure 2 and provides an example of determining the weighting of one NCTM process standard based on the sequential linearity; in this case, we determine the weighted value of the learning process *Communication*. Herein, 10 links connect the 5 *Es* to the descriptive characteristics and the sum of these weighted links is 31. Thus, the average of the weighted links going from the 5 *Es* to *Communication* is $31 \div 10 = 3.1$.

Altogether, then, Figure 2 produces the following weighted averages for each of the NCTM process standards: *Problem Solving* = 12/4 = 3; *Reasoning* = 12/6 = 2; *Communication* = 31/10 = 3.1; *Connections* = 13/4 = 3.25; *Representations* = 3/1 = 3. Using this scoring, in ascending numeric order, the mathematics learning processes fell into the alignment: *Reasoning*, *Problem Solving* and *Representations*, *Communications*, and *Connections*. This scoring mechanism could argue that the NCTM process standards have a characteristic of linearity and that the natural order of learning and doing mathematics should follow this sequence.

Although it can now be quantitatively argued that mathematics may possibly be more linear and sequential than usually recognized in the literature, the closeness of the scores may indicate that the linearity of the mathematics learning processes is not strong. Nevertheless, educators should plan instruction by simultaneously holding to the philosophical understanding that the mathematical learning processes are to be continually interwoven with all processes taking equal billing and that the natural process of mathematical learning may indeed be somewhat sequential and follow the path from *Reasoning*, to *Problem Solving* and *Representations*, *Communications*, and *Connections*. Thus, educators may need to balance philosophy with pragmatism in determining the most effective instructional activities for the classroom.

The possible lessened linearity of the science learning processes found that this analysis may indicate a need for science educators to reconsider curriculum and instruction. The sequence of the 5 *Es* has long been a habit of understanding and practice within the community of science education. However, lessened linearity may indicate that science lessons should be more free-flowing and less structured to meet the sequence of the 5 *Es*. In so doing, however, it should be realized that within any science learning activity all components of the 5 *Es* will naturally be experienced by students as they learn science.

Summarily, this analysis may imply that instruction in both mathematics and science may need to be reconceptualized. Learning activities may need to be planned within each area of study with an understanding of linearity and nonlinearity among the respective learning processes. While this may lead to lessons of

unfamiliar form and countless curricular reforms, it may also eventually provide curriculum and instruction that are more aligned with how students actually learn each content area.

Problem-Solving Path

Further analysis of the central column of Figure 2 brings an additional dimension to light. Without planning such, the list of characteristics of the mathematics and science learning processes may have fallen into a natural sequence more fully denoting the problem-solving process. The conventionally accepted sequential linearity of the 5 *Es* may have had some causal effect on this listing. This list includes:

1. Task Engagement and Generating Curiosity
2. Disequilibrium
3. Predicting, Hypothesizing, Investigating
4. Systematic Exploration; Mediated Investigation; Organize Student Thinking
5. Making Connections Between Past and Present Learning Experiences
6. Peer-Mediated Development
7. Multimodal
8. Formal and Informal Language and Communication
9. Justify and Defend Solutions; Reasoning; Synthesize Ideas
10. Demonstrate Conceptual and Procedural Understanding
11. Use Internal and External Connections and Relationships; Solidify Understanding
12. Apply Understanding; Extend Knowledge to New Ideas and Future Investigations
13. Model Making

This list is notably more extensive than Polya's four-step problem-solving strategy (Polya, 1957) that includes Understanding the Problem, Devising a Plan, Carrying Out the Plan, and Looking Back. Although the list above explicitly denotes a number of dimensions that do not need to be further examined, the list also inherently and tacitly considers additional dimensions such as: affective concerns (student interest and participation); social concerns (interaction, communication, and collaboration with others); multiple representations (as a tool for problem solving and communication); language and communication in problem solving; and generalizing (extending problem solving findings to novel ideas). This problem-solving sequence together with these embedded dimensions can reinvigorate discussions regarding the importance of problem solving in the learning process and the multifaceted nature of problem solving.

While it is beyond the scope of this discussion to more fully examine each stage in this problem-solving sequence, this list can be used by educators in their planning of instruction centered on problem-solving experiences. Without further explication, most science and mathematics educators should be able to recognize the meaning and nuances within each stage in the sequence and be able to develop instructional materials and classroom activities that give students the opportunity to experience problem solving as a valuable learning process.

Implications

Simultaneously considering both the extensive similarities and the little dissimilarity between the mathematics process standards and the 5 *Es* of science strongly argues for the integrated teaching and learning of mathematics and science. Additionally, it can be argued that the little dissimilarity is complementary to each respective field and works to further bolster and expand the distinct content areas. Altogether, therefore, teachers should develop rich integrated learning activities through which mathematics and science will be learned and, in so doing, in the learning of mathematics, students will also experience those characteristics unique to the learning of science and vice versa. This will strengthen the learning experience of each field by providing experiences that will stretch the learner.

Integrated mathematics and science curricula, although unusually common, are far from novel. Unfortunately, few historic and current endeavors have argued, in respect to student learning, why these two subjects should be integrated. Herein, we proffer that an argument for the curricular integration of the two fields can be made based on the similarities of the learning processes associated with each. Rather than stating that these subjects are alike, this investigation has discovered that they are learned in like manner; therefore, it is appropriate that they be taught and learned together.

Unfortunately, reform of mathematics and science curricula to be significantly integrated is a complex task. In addition to creating new curricular materials, teacher preparation and professional development would need to radically change. Many teachers would need to be cross-trained. While the entire process of truly integrating mathematics and science instruction

would tax curriculum developers, university teacher education programs, school systems, and teachers, it may be warranted and glean far greater benefits in student learning.

Conclusion

This investigation has discovered significant similarity between the process standards in the *Principles and Standards for School Mathematics* (NCTM, 2000) and the 5 *Es* of the *National Science Education Standards* (NRC, 1995). Findings from such include the sequential linearity and nonlinearity of these learning processes, affective and social concerns, and the value for integrating curriculum and instruction in mathematics and science education. Notably, this article proposes no particular model for curricular integration; rather, the authors only proffer an additional rationale supporting the integration of mathematics and science instruction and learning. It is hoped that this discussion serves the educational community by promoting more investigation into learning processes and the integration of subject matter instruction and that these findings will help others develop new and effective models of integrated curricula.

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The Rise and Fall of Science Education: A Content Analysis of Science in Elementary Reading Textbooks of the 19th Century

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In the 19th century the textbook dominated the curriculum and methods of instruction. The most important textbook was the textbook of reading known as the reader. In the early 1800s science was not established as a separate primary grade subject. The science students encountered in these reading textbooks may have been their only formal science education. This study used content analysis to determine the type of science and the quantity of science in popular U.S. readers of the 19th century. The percent of science rose in the middle of the century and declined at the end. This decline may have been due to the desire to make the study of reading literary based. The percentage of science that was biological increased throughout the century, and the percentage of Earth science declined.

While textbooks play a major role in American schools today, in the 19th-century textbooks were the curriculum, the course of study, the method, the way students learned. In the early grades this period's dominant textbook was the textbook of reading called the reader. Students developed reading skills from readers, and they learned aspects of the world that leaders in education deemed most important. The readers contained stories and articles pertaining to literature, history, ethics, religion, and science.

The origins of elementary science education in the United States can be traced to these readers. In the early 19th century, science was not taught as a separate subject in the beginning grades. Children were exposed to school science through their reading textbooks. The analysis of science in early readers used in U.S. schools is therefore important in understanding the origins of American elementary science education.

The intent of this study was to analyze and describe a key stage in the history of science education. Focusing on the 100-year period of the 19th century, the study analyzed the science in readers. Content analysis protocols were used to examine popular 19th-century readers for the relative quantity of science, types of science, and method of presentation.

Historical Context

Textbook as the Curriculum

Education in the United States is and was dependent on textbooks (Altbach, 1991; Wong & Loveless, 1991). In modern educational systems "textbooks are frequently the student's major source of information on a particular subject taught in school, and may even constitute the only exposure the student receives on a given topic" (Keith, 1991, p. 43). "Textbooks help define school subjects as students experience them. They represent school disciplines to students" (Valverde, Bianchi, Wolfe, Schmidt, & Houang, 2002, p. 1). "At all levels of schooling Science textbooks are often used as the primary organizer of the subject matter that students are expected to master and provide detailed explanations of topics to be taught" (Chiappetta & Fillman, 2007, p. 1847).

Textbooks were extremely important in 19th-century education systems; they were not only the curriculum but also the method of instruction. In 1880, William T. Harris, who later became the U.S. Commissioner of Education, concluded that

> "Text-book instruction" is the form of school instruction adopted by the deep instinct of modern society, as the most direct and effective method of initiating the individual man into spiritual participation in the activity of his race. By it our system of instruction is best enabled to secure what is substantial without sacrificing the formal (Harris, 1880, p. 9).

The importance of textbooks was due in part to the large number of untrained and poorly educated teachers in the classrooms (Elson, 1964; Nietz, 1961). From the start, these teachers relied heavily on familiar textbooks. A 19th-century author suggested that teachers should prepare better by reading the textbook prior to class (Elson). The textbook more than dominated the curriculum, it was the curriculum—it represented the

course of study (Nietz). Samuel G. Williams wrote in 1892, in *The History of Modern Education:*

> Should specimens of our pedagogical treatises, essays, and periodicals, of our proceedings, reports, and text-books, fall into the hands of the historian of some coming century, in any reasonably complete form, he will doubtless credit us with a degree of literary activity in the realm of pedagogy hitherto unprecedented—while possibly expressing mild surprise that we apparently laid so much stress on text-books (p. 390).

Knowing the contents of current textbooks is important for understanding modern education (Calhoun & Rubba, 1993; Eltinge & Roberts, 1993; Keith, 1991; Tyson-Bernstein & Woodward, 1991). Knowing the content of past textbooks is important for understanding the history and current state of education.

> Most authorities agree that in the United States the old textbooks in use in any particular school largely constituted the school's course of study. And so an analysis of old American school textbooks reflects the evolution of the American school curriculum and the teaching and learning methods (Nietz, 1961, p. 1).

Readers as the Textbook

Common schools evolved into today's elementary schools. Readers—reading textbooks consisting of short articles or lessons—were common schools' most important textbooks. Instruction in primary schools focused on spelling, reading, and writing, and through the age of six, most of the instruction in these three areas was in reading (Soltow & Stevens, 1981). Teaching students to read so they could read the Bible was the primary purpose of early Puritan schools in America (Vaughan, 1972).

While a variety of textbooks were in existence, readers were the most used. In an 1828 report on the common schools in Connecticut, the numbers of books in use were as follows: 29 reading, 10 geography, 8 spelling, 8 arithmetic, 6 grammar, and 5 history books (Belok, 1973). The larger variety of readers published as compared with other textbooks indicates their importance in common school education. The McGuffey Readers alone were estimated to have sold 60 million books during the period of 1870–1890 (Nietz, 1961, p. 73). These books were often shared by students and passed from one family member to another. Mathews (1966) suggests multiplying sales figures by four or five to obtain the total amount of students using the readers.

Reading was the most important subject, and readers were the most important textbooks. Compilers of readers, such as William H. McGuffey and his famous McGuffey Readers, aimed to educate students in other areas of life. They selected articles to achieve these aims, and these were generally between one and four pages in length. The selections presented a diverse range of subject material including literature, history, geography, ethics, religion, and science. As they were designed to help students learn, these selected articles will be referred to as lessons.

The Beginning of Science Education

The focus of early schools was on reading, writing, and arithmetic. There were no science textbooks, and science was not taught as a separate subject (Underhill, 1941). Students learned about science through content area selections in the readers. Thus, the science in readers was the origin of American elementary science education.

The science lessons in the readers of the first few years of school were students' first exposure to school science. Most students did not attend school past the first several years. Prior to 1890, only 3.8% of the population between 14 and 17 years of age enrolled in school (Hurd, 1961). Thus, for many 19th-century American school children, the science selections in the primary readers may have been the only formal science education encountered. The science in these readers was for all students the first school science experience, for many it was the only science experience, and from a historical perspective it was the cradle of American science education.

Methods

Historical methods of inquiry are used to find past trends that can lead to deeper understandings of the present. Within this context of inquiry, content analysis protocols were used to examine science in popular 19th-century readers. Content analysis is described by Berelson (1952) as "a research technique for the objective, systematic, and quantitative description of manifest content of communications" (p. 74). The analysis was used to determine the percentage of science in the readers, both by page and by lesson. The science lessons were further classified into three branches of science: biological sciences, Earth

sciences, and physical sciences. The most popular 19th-century readers were analyzed for 20-year intervals.

Content Analysis

This study followed protocols of Selltiz, Jahoda, Deutsch, and Cook (1986) for content analysis—a method for analyzing communication content. The study was designed to answer two questions: (1) How much science existed in popular 19th-century readers? and (2) What kinds of science were presented? The main category and coding unit for the quantitative classification was science, which was further divided into coding units of biological, Earth, and physical sciences.

In assessing if the lesson was about science, should the main point of the lesson present scientific information, for example about an organism or a structure of the Earth, then the lesson was judged to be scientific in nature. The science content was further classified into the type of science: biological, Earth, or physical science. Biology consists of zoology, botany, and physiology. Earth science consists of physical geography, geology, meteorology, and astronomy. Physics and chemistry are the subjects of physical science. These subject groupings are almost identical to the groupings made for science conferences in 1892 for the Committee of Ten (National Education Association, 1893). The only difference is that astronomy was placed with physics and chemistry in the Committee of Ten report.

Popular 19th-century readers were analyzed page by page. The study analyzed 8,459 pages, which contained 3,875 different selections or lessons. The number of science lessons in the readers and the number of pages of these lessons were systematically tabulated. Lengths of the lessons were recorded to the nearest quarter of a page. The data were summarized by a 20-year period and expressed as science percentage by total lessons and by total pages. Qualitative content analysis was used to determine how science was presented. These categories were not developed prior to the analysis of readers. A variety of modes of transmission emerged in the study; these are reported but not quantified.

Reader Selection

A purposive selection of the most representative readers of the 19th century was used in this content analysis. The most popular readers were selected to best represent the textbooks of an era because they were the most commonly used and most often imitated. Weak copyright laws and enforcement in the 1800s allowed reader compilers to use the same articles or lessons. As might be expected, the most successful readers were the most copied and imitated. For these reasons this study used the most popular readers in the 19th century.

A synthesis of expert opinion was used to develop a list of the most popular readers. Methods to assess the popularity of the readers include ascertaining the number of copies sold, the number of editions published, and recommendations of school boards (Smith, 1967). Carpenter (1967), Lamport (1937), Nietz (1961), Reeder (1900), and Smith wrote important books involving American readers. Each author indicated which readers he or she considered most popular in the 19th century. For this study, the works of these authors were interpreted in order to arrive at a list of the most popular 19th-century readers in 20-year intervals. These books are listed in the Appendix.

In the case of readers that came in a graded series, only the first three books are analyzed. These provided children with their first formal exposure to science. Children who completed the first three books were considered well educated. In the middle part of the 19th century, "children who attended school regularly in the primary grades achieved a level of reading of approximately that found in *McGuffey's Third Reader*" (Soltow & Stevens, 1981, p. 102). This was a significant achievement. Nietz (1961, p. 77) reports the vocabulary of McGuffey's second reader to be at the eighth-grade level. "Most nineteenth century students [only] completed the second reader before leaving school, but many left before completing the third. Anyone who completed mastery of the fourth reader was considered well educated" (Lindberg, 1976, p. xv).

Results

Science Quantity

Science content is significant in the readers of all the periods in the 19th century. The mean amount of science in readers during this 100-year period was 12.76% of the total page contents. The mean percentage of the lessons devoted to science was 14.25%.

Science content in the readers increased in amount from the beginning of the century, peaking in the middle of the century (Figure 1). At the beginning of the century the mean science content of the book was only 3.86% of the pages. This amount reached a peak of 19.62% in the 1840–1859 period. The percentage of

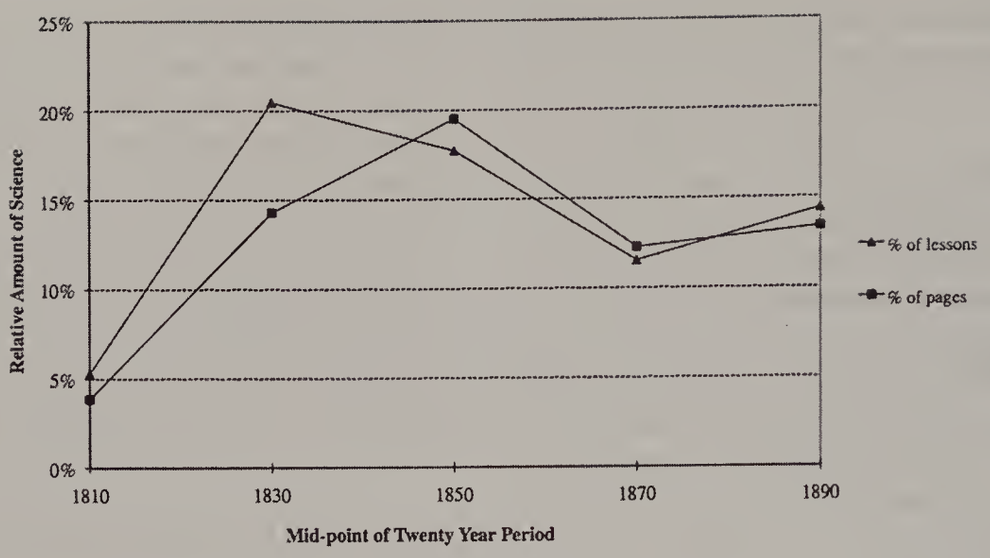

Figure 1. The percentage of science in readers by 20-year periods.

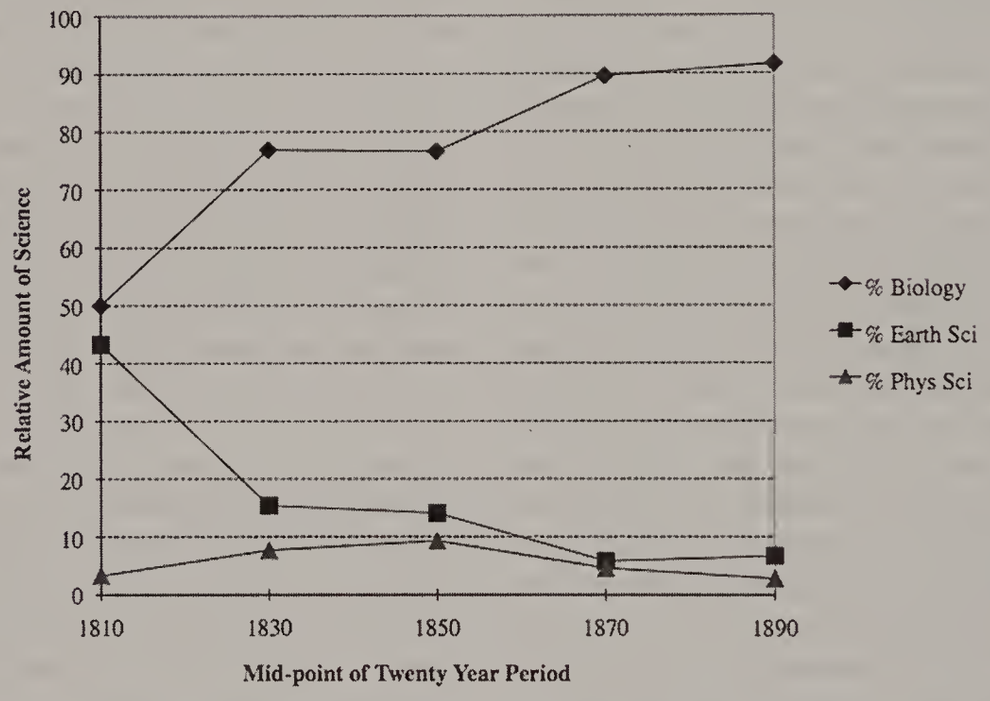

Figure 2. The percentage of the type of science in readers by 20-year periods.

science lessons in the readers started at 5.28% and peaked in the 1820–1839 period at 20.47%.

The science content that was biological rose constantly during the century (Figure 2). At its beginning, biology represented 53.3% of all of the science lessons, however at the end of the century, biology represented 90.5% of all of the science. The increase in biology content roughly follows the decrease in Earth science content. Earth science decreased during the 100 years from 43.33% to 6.74%. Physical science started the century at 3.33% increased to 9.27% during the middle of the century and closed the century at 2.8%.

Modes of Presentation

Science was presented in readers in a variety of forms. Sometimes the presentation was a straightforward explanation of facts, which is common in science textbooks of today. However, science was also presented in dialogues between adults and children, in story form, and in poetic form. In some lessons, science was united with literature, morality, or religion lessons.

While frequently the science lessons stood alone, efforts were sometimes made to unite them with other types of lessons. For example, a scientific description would sometimes precede a story about an organism or a natural event. In Baldwin's (1897) second-year reader, there is a biology lesson describing rabbits and turtles with the subsequent lesson being the classic fable about the tortoise and the hare. In McGuffey's (1853) third reader a scientific lesson on thunderstorms precedes a poem describing the stillness before a storm and then the fierceness of the storm.

Morality lessons were very much a part of the readers of the 19th century. Stories were used to promote honesty, hard work, patriotism, and societal values. Almost all of the readers contained multiple lessons designed to prevent cruelty to animals. For the purposes of coding, if these lessons did not present biological information they were considered to be morality lessons and not biology lessons. Some lessons combined biology with morality. For example, in Hillard and Campbell's (1864) third reader is the lesson "Thoughtless Cruelty" in which an uncle expresses his displeasure with his nephew for throwing stones at birds. The uncle then proceeds to describe unique biological aspects of birds. The lesson ends with "Remember, therefore, that God has made the birds as well as you, and that He cares for them as well as for you" (Hillard & Campbell, p. 93).

Some reader selections, including science lessons, emphasized religious interpretations. God was frequently mentioned and praised in the lessons. In a lesson entitled "The Nettle," which appeared in McGuffey's (1853) third reader, a father tells his daughter about botany and nettles and their uses after she was "stung" by one. He ends by saying, "Thus, you see, that even the despised nettle is not made in vain; and this may teach you, that we only need to understand the works of God, to see that, 'in goodness and wisdom he has made them all' " (p. 46). In Sanders' (1843) first reader, a selection depicts children's fascination with fireflies. The mother tells them at the end, "the earth is full of the works of the Lord, and no life is long enough to learn them all" (p. 82).

Discussion

Rise in Science Content

The science content in readers increased in the first half of the 19th century. To be sure, there are many potential reasons for this, and it is difficult to establish cause-and-effect relationships in this type of study. This increase, however, could reflect society's increased interest in science. The 19th century was a period of great scientific achievements, professionalization of scientists, and popularization of science. Many famous names of physical science made their contribution during this century, including Joule, Kelvin, Galvani, Volta, Ampère, Maxwell, Oersted, and Hertz (Williams, 1909), and their works were available in English. In the biological sciences during the 19th century, "the germ theory of diseases was established, the foundation was being laid for the theory of genetics, and evolutionary theories were being formulated" (Underhill, 1941, p. 94). The field of medicine became professionalized and the American Medical Association was established in 1847 (Browner, 2005). Technological developments were being made at a rapid pace. Before 1840 only a few hundred patents were issued per year, from 1840 to 1850 there was an average of 646 per year, and in the next decade this grew to 2,225 per year (Coman, 1905).

Science became very popular. In the decade of the 1830s, there was the emergence of "widespread science coverage in newspapers, and numerous lyceum lectures in science" (Nadis, 2005, p. xii). It is during this period that *The Scientific American* (1845) and *Popular Science* (1872) were established (Stableford, 2006). The popularity of science probably contributed to the great inclusion of science in the readers.

Decline in Science Content

The rise in science content from the beginning to the middle of the century probably reflects the increasing popularity of American science. The question that must be asked is why did the relative amount of science in readers decrease as the century continued?

Movement to Make Reading Instruction Literature Based. The decrease may be due to a desire of some educators to use literary readings rather than factual readings as a way of teaching reading. Leading the campaign was Charles Eliot, president of Harvard University, who wrote in 1891 that he objected to readers because they are not real literature (Smith, 1967). The Conference on the Study of English of the Committee of Ten recommended, "Reading-books should be of a literary character and should not attempt to teach physical science or natural history" (National Education Association, 1893, p. 89).

The reduction of science in readers of the last part of the 19th century may have been a backlash against the large amount of science being used in some readers.

Reeder (1900) discusses the readers of Marcius Wilson, which were heavily laden with science. For example, in Wilson's third reader there are only three subject headings: stories from the Bible, moral lessons, and zoology including the class mammalia. Reeder states that Wilson's books helped settle the debate as to what should be the central core of a reading series.

> The Wilson series showed the absurd limit to which the utilitarian principle might lead, and the necessity for finding the true center for this branch of curriculum. In the struggle for the central position, literature gradually emerged from the conflict triumphant over those subjects which are confined within the limits of time and space, and in the new series and supplementary readers which began to appear about 1880, literature took the field, and since then has held it against all comers (p. 160).

Establishment of Science as a Separate Subject. The movement to establish science as a separate subject may have been a participating factor in the reduction of the quantity of science in readers. While science grew in popularity, science was not yet established as a separate subject in the elementary grades. Scientists in the last decades of the 19th century advocated teaching science as a separate subject in the elementary schools (Underhill, 1941). From its origins in object teaching and nature study, science was on its way to becoming an independent area of the elementary curriculum (Rillero, 1993; Underhill). According to the United States Commissioner's Report for 1880–1889, cities such as Kansas City, Chicago, Cincinnati, and Milwaukee had no science courses below sixth grade, while others devoted from .7% (Detroit) to 9.7% (Washington, DC) of instructional time to science (Underhill). As science started to become a subject in its own right, compilers may have felt a reduced need to include science selections in readers.

Science Content in Readers

Rise of Biology. This study found that the percentage of science in 19th-century readers that was biological in nature steadily grew. The rise in biological sciences might be attributed to writers getting people interested in nature, the object teaching movement, and the nature study movement.

Nineteenth-century writers' popularization of the living world may have caused an increase in biological content in the readers. Rousseau and other romantic writers after him were influential in creating a feeling of wonder for nature (McCulloch, 1979). The popularization of the natural world led to two educational movements: object method of teaching and nature study.

Object teaching was strongest in the years 1860–1880 and is generally accepted as the forerunner of elementary school science (Rillero, 1993; Underhill, 1941). It used the study of real things and phenomena as an integral part of education. Objects that were interesting to children and readily available were used. Living organisms such as flowers, trees, birds, and even the human body fit into this category. A report by the National Teachers' Association in 1865 indicates that the Pestalozzian method of object teaching had influenced reading (Robinson, 1930). Hollis, in 1898, uses his observation of the change in textbooks in the 30 previous years as an example of the great popularity of the Oswego-based object-teaching reforms. The number of lessons dealing with aspects of the world around them seems to have increased because of object teaching. A large number of lessons in object teaching dealt with the living world. Thus, object teaching may have influenced the increase in biology in readers.

The nature study movement reached its peak in the years 1890–1920 (Mickenberg, 2006). This educational movement sought to cultivate a love of nature by leading students to firsthand observations of the nature world. The popularity of nature study may have induced compilers of readers to increase the amount of biology in their books.

Decline in Earth Science. While biology increased, the Earth science in readers decreased. This may have been because biology became a more popular subject. However, Earth sciences may have decreased in readers because geography textbooks became readily available as geography appeared as an independent subject. Finney (1921) points out that geography had little place in the common schools in the 1820s. However, it gained steadily throughout the century, and geography secured a recognizable place in the elementary school after the Civil War (Finney). In 1893, the Committee of Ten stated, "geography has been a subject of recognized value in the elementary schools for many generations" (National Education Association, 1893, p. 31). Special geography textbooks or geography readers were used in teaching this subject (Nietz, 1961). The geography books contained

Earth science topics such as astronomy, winds, tides, and soils. As geography secured a place in the elementary curriculum, compilers of readers may have decided to decrease the amount of Earth science material. More research needs to be done on how geography later morphed with a greater focus on social sciences and a lesser emphasis on physical geography and the implications of this for children learning Earth science.

Physical Science. Considering the success of the industrial revolution, it is surprising that more physical science was not present in the readers. However, as Soltow and Stevens (1981) state, "in the early nineteenth century there is no doubt that tradition weighed more heavily than change" (p. 96). Compilers of readers may have neglected the physical sciences because they require greater mathematical background than young students may have had. Also, they can be less visual than either the biological or Earth sciences.

Science in Modern Readers

While changes have been made in reading instruction, the basal reader is still strong. "For at least the last twenty-five years, over 90 percent of elementary school teachers use basals over 90 percent of the time during reading instruction" (Shannon, 1991, p. 223).

A study of contemporary readers by Flood and Lapp (1987) identified the amount of science and science by subject area these readers contained. Of the readers they examined, 17.5% contained expository writing, of which 33% was scientific. Assuming nonexpository writings (e.g., narrative, poetry, plays, biography, hybrid) to contain minimal science, the average amount of science in the contemporary reader is 5.8%. This is a decline from the 14.4% at the end of the 19th century.

How does the coverage of science content areas in readers for the 19th century compare with modern readers? In Flood and Lapp's (1987) analysis of the type of science in the expository selections of readers, 58.9% of the science selections were life science, 21.8% Earth science, and 19.3% physical science. Like 19th-century popular readers, biology is the most presented science subject, followed by Earth science, and then physical science. However, in modern readers the amount of biological science has decreased, as Earth science and physical science selections have increased.

Conclusion

An analysis of content in American 19th-century readers shows not simply what educational leaders thought should be taught but what was actually taught (Nietz, 1961). An average of 12.76% of the 19th-century reader pages were devoted to science. The amount of science peaked in the middle of the century. While many factors may have been involved, the greater emphasis on literature was a critical influence in helping push science out of the readers.

In the mid-19th century science was firmly embedded in the first "R" of the three "Rs" of education, and students received significant science education in their reading. As science was pushed out of readers it began gaining credibility as a stand-alone subject. Science education was free to evolve into more than just something to read about, and it could grow as a subject for children to directly examine the living world and nonliving materials. Yet it has never shaken its roots as a subject in a textbook. Unfortunately, as science was pushed out of readers, it was also pushed out of the day-to-day school experiences of many primary grade children. And it has not returned.

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Author's Notes

I would like to thank the education libraries of The Ohio State University, Miami University, the State University of New York at Oswego, and Arizona State University for preserving their rare books and allowing me access.

Appendix

Bibliography for Readers used in Quantitative Analysis of Science Content

Organized by Year of Publishing

1800–1819

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Bingham, Caleb. (1805). *The American Preceptor; Being a New Selection of Lessons for Reading and Speaking. 23rd edition*. Boston: Manning and Loring.

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1820–1939

Murray, Lindley. (1826). *The English Reader; or, Pieces in Prose and Poetry, Selected from the Best Writers*. Philadelphia: Edwin T. Scott.

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PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the Journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to 972-86-477-648. Questions concerning proposals and/or solutions can be sent e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before September 15, 2010.

• **5116:** *Proposed by Kenneth Korbin, New York, NY*

Given square $ABCD$ with point P on side AB, and with point Q on side BC such that

$$\frac{AP}{PB} = \frac{BQ}{QC} > 5.$$

The cevians DP and DQ divide diagonal AC into three segments with each having integer length. Find those three lengths, if $AC = 84$.

• **5117:** *Proposed by Kenneth Korbin, New York, NY*

Find positive acute angles A and B such that

$$\sin A + \sin B = 2\sin A \cdot \cos B.$$

• **5118:** *Proposed by David E. Manes, Oneonta, NY*

Find the value of

$$\sqrt{2011 + 2007\sqrt{2012 + 2008\sqrt{2013 + 2009\sqrt{2014 + \ldots}}}}$$

• **5119:** *Proposed by Isabel Díaz-Iriberri and José Luis Díaz-Barrero, Barcelona, Spain*

Let n be a nonnegative integer. Prove that

$$2 + \frac{1}{2^{n+1}} \prod_{k=0}^{n} \csc\left(\frac{1}{F_k}\right) < F_{n+1}$$

where F_n is the n^{th} Fermat number defined by $F_n = 2^{2^n} + 1$ for all $n \geq 0$.

• **5120:** *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

Calculate

$$\lim_{n\to\infty}\frac{1}{2^n}\sum_{k=0}^{n}(-1)^k\binom{n}{k}\log\left(\frac{2n-k}{2n+k}\right).$$

• **5121:** *Proposed by Tom Leong, Scotrun, PA*

Let n, k, and r be positive integers. It is easy to show that

$$\sum_{n_1+n_2+\cdots+n_r=n}\binom{n_1}{k}\binom{n_2}{k}\cdots\binom{n_r}{k}=\binom{n+r-1}{kr+r-1},\ n_1, n_2, \cdots, n_r \in N$$

using generating functions. Give a combinatorial argument that proves this identity.

SSM Publication Guidelines

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School Science and Mathematics Journal
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Frequency of issue: 8 times per year
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No. of in-house reviewers: Up to three
Fees charged to review: None
Editor considers recommendations of reviewer: Yes
Time to review: 6-7 months
Reviewers' comments: Yes
Invited articles: 5% or less

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Research manuscripts only:

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Analyses of data
Conclusions based on results
Results related to professional practice and literature
Enough information to enable replication (quantitative)

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SCHOOL SCIENCE AND MATHEMATICS

Volume 110 • Number 6 • October 2010

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Official Journal of the School Science and Mathematics Association, Founded 1901

School Science and Mathematics

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(All publication matters except advertising and reprints)
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School Science and Mathematics (Print ISSN: 0036-6803, Online ISSN: 1949-8594) is published in January, February, March, April, September, October, November and December on behalf of the School Science and Mathematics Association by Wiley Subscription Services, Inc., a Wiley Company, 111 River St., Hoboken, NJ, 07030-5774. Periodical postage paid at Hoboken, NJ and additional offices.

Postmaster: Send all address changes to *School Science and Mathematics*, Journal Customer Services, John Wiley & Sons, Inc., 350 Main St., Malden, MA 02148-5020.

Information for Subscribers: *School Science and Mathematics* is published in eight issues per year. Subscription prices for 2010 are: Institutional Print & Online rate: US$250 (the Americas), US$250 (Rest of World), €180 (Europe) £153 (UK). Prices are exclusive of tax. Asia-Pacific GST, Canadian GST and European VAT will be applied at the appropriate rates. For more information on current tax rates, please go to www.wileyonlinelibrary.com/tax-vat. The institutional price includes online access to the current and all online back files to January 1, 1997, where available. For other pricing options, including access information and terms and conditions, please visit www.wileyonlinelibrary.com/access.

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Production Editor: John Siever (ssm@wiley.com)

Electronic Access: This journal is available online at *Wiley Online Library*. Visit http://wileyonlinelibrary.com/ to search the articles and register for table of contents and email alerts.

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ISSN: 0036-6803 (Print)
ISSN: 1949-8594 (Online)
Printed in the US by The Sheridan Group.

IN THIS issue

Original Articles

Efficacy for Teaching Elementary Science and Mathematics Compared to Other Content

Ray R. Buss

The study was conducted to examine preservice, elementary teachers' efficacy for teaching science and mathematics as compared with other elementary content. The instrument assessed efficacy for teaching (EFT) five elementary content areas: science, mathematics, reading, classroom management, and general instruction. Three hundred and twenty-five preservice elementary teachers completed a 15-item instrument assessing efficacy for teaching in these five areas. The instrument was found to be valid and reliable. Overall group results indicated participants' EFT science and mathematics were lower than for teaching other areas. Intra-individual patterns showed there were six clusters, including a group with low EFT mathematics and a group with low EFT mathematics and science. Implications for preservice teacher preparation opportunities and experiences are discussed.

Evaluating Mathematics Achievement of Middle School Students in a Looping Environment

Dana Pomykal Franz, Nicole L. Thompson, Bob Fuller, R. Dwight Hare, Nicole C. Miller, Jacob Walker

Looping, a school structure where students remain with one group of teachers for two or more school years, is used by middle schools to meet the diverse needs of young adolescents. However, little research exists on how looping affects the academic performance of students. This study was designed to determine if looping influenced middle school students' mathematical academic achievement. Student scores on the Mississippi Curriculum Test (MCT) were compared between sixth and eighth grade years for 69 students who looped during the seventh and eighth grades with a group of 137 students who did not loop. Looping students achieved statistically significantly greater growth on the MCT than their nonlooping counterparts between sixth and eighth grades. Further, the data were disaggregated by gender, ethnicity, and socioeconomic status. Findings indicate that looping may academically reengage students during the middle school years. Advantages and disadvantages of looping at the middle grades are discussed.

Exploring the Link between Reformed Teaching Practices and Pupil Learning in Elementary School Mathematics

Cindy Jong, Joseph J. Pedulla, Emilie Mitescu Reagan, Yves Salomon-Fernandez, Marilyn Cochran-Smith

This study examined the classroom practices of beginning elementary school teachers' instruction of mathematics and how it connected to their pupils' learning. The Reformed Teaching Observation Protocol (RTOP) was used to measure the extent to which beginning teachers used reformed teaching practices. As a measure of pupil learning, we utilized assessment scores specific to the mathematics unit observed and correlated it with teachers' RTOP scores. We found that beginning teachers who implemented reformed teaching practices tended to have pupils who scored higher on the district mathematics test with a statistically significant correlation of .56 ($p < .05$). Implications of these findings and others are discussed in terms of using the RTOP to improve practice at the elementary school level and for future school-based research.

Efficacy for Teaching Elementary Science and Mathematics Compared to Other Content

Ray R. Buss
Arizona State University

The study was conducted to examine preservice, elementary teachers' efficacy for teaching science and mathematics as compared with other elementary content. The instrument assessed efficacy for teaching (EFT) five elementary content areas: science, mathematics, reading, classroom management, and general instruction. Three hundred twenty-five preservice, elementary teachers completed a 15-item instrument assessing efficacy for teaching in these five areas. The instrument was found to be valid and reliable. Overall group results indicated participants' EFT science and mathematics were lower than for teaching other areas. Intra-individual patterns showed there were six clusters including a group with low EFT mathematics and a group with low EFT mathematics and science. Implications for preservice, teacher preparation opportunities and experiences are discussed.

As professional organizations (National Council of Teachers of Mathematics [NCTM], 2000; National Research Council [NRC], 1996) seek to improve the teaching of science and mathematics through the application of more rigorous standards, the preparation of preservice teachers who can teach effectively to aid their students in attaining levels of performance to meet these standards becomes increasingly important. Nevertheless, both anecdotal evidence as well as research (Appleton, 2003; Mulholland & Wallace, 2000; Swars, 2005; Swars, Daane, & Giesen, 2006) indicate preservice teachers' concerns about their abilities to effectively teach elementary school science and mathematics. As a result, the current investigation was conducted to examine the initial efficacy of preservice teachers for teaching science and mathematics and compare their efficacy for teaching these areas with other elementary school content areas such as reading, classroom management, and general instruction.

The investigation of efficacy beliefs about teaching elementary school science and mathematics has been the focus of a considerable amount of research over the past 15 years (Cakiroglu, 2008; Cakiroglu, Cakiroglu, & Boone, 2005; Enochs & Riggs, 1990; Enochs, Scharmann, & Riggs, 1995; Enochs, Smith, & Huinker, 2000; Mulholland, Dorman, & Odgers, 2004; Swars, 2005; Utley, Bryant, & Moseley, 2005). Enochs and Riggs' seminal study of efficacy for teaching science using the Science Teaching Efficacy Belief Instrument—Preservice (STEBI-B) has generated a vast number of studies exploring that area (e.g., Cakiroglu et al., 2005; Enochs et al., 1995; Mulholland et al., 2004; Utley et al., 2005). Enochs and Riggs developed the STEBI-B based on Bandura's (1977) social cognitive theory, which includes self-efficacy *and* outcome expectancy. As a result, the STEBI-B consists of two scales—Personal Science Teaching Efficacy (PSTE, 13 items) and Science Teaching Outcome Expectancy (STOE, 10 items). PSTE is defined as an individual's personal beliefs about how effectively she will teach science. On the other hand, STOE is concerned with how the instruction will affect science achievement of students. An example of a PSTE item is, "I know the steps necessary to teach science concepts." By comparison, an example of a STOE item is, "Students' achievement in science is directly related to their teacher's effectiveness in science teaching." Generally, results indicate significant increases from pre- to post-test situations for PSTE as a result of taking a science methods course, participating in student teaching, completion of science coursework, etc. On the other hand, the STOE measure typically remains stable from pre- to post-test situations. The reason for the differences in efficacy and outcome expectancy changes has to do with the extent to which the prospective teacher perceives she has control of the situation. Although a prospective teacher may expect to teach science effectively, she may not feel she can exercise much control over whether students learn the information or are able to use it in a substantive way after instruction (Bandura, 1997; Tschannen-Moran, Woolfolk Hoy, & Hoy, 1998).

Others have adapted the STEBI-B to assess efficacy in other areas, most notably mathematics (Enochs et al., 2000). The revised instrument is called the Mathematics Teaching Efficacy Belief Instrument and consists of 21 items. The efforts in this area consist of

primarily recent work (Cakiroglu, 2008; Enochs et al., 2000; Swars, 2005). Results are similar to those for science teaching since Personal Mathematics Teaching Efficacy (13 items) increased from pre-to post-test and Mathematics Teaching Outcome Expectancy (8 items) remained stable from pre- to post-test. In contrast to the extraordinary efforts in examining EFT for science and the modest efforts with respect to EFT mathematics, much less is known about EFT-specific content areas such as reading, general instruction, and classroom management.

The few studies that have been conducted to examine EFT in other elementary content areas have been carried out by Wingfield and her colleagues (Wingfield, Nath, Freeman, & Cohen, 2000; Wingfield, Nath, Henry, Tyson, & Hutchinson, 2000). They examined preservice teachers' personal teaching efficacy for elementary content areas and their outcome expectancy for those content areas by modifying the STEBI-B. The researchers replaced the word "science" with, for example, the words "language arts," and "mathematics" and asked students to respond to items on these instruments. Students completed modified language arts and mathematics versions of the STEBI-B at the beginning and end of a semester that included methods courses in a Professional Development School setting.

In the first study, results indicated preservice teachers' scores increased significantly from pre- to post-test on personal teaching efficacy beliefs for language arts, but not on outcome expectancy measures. In the second investigation, Wingfield, Nath, Freeman, et al. (2000) used the previously gathered data and they also collected efficacy beliefs and outcome expectancy data for teaching mathematics. Results from the mathematics portion were similar to those for language arts with an increase in teaching efficacy and stable outcome expectancy. Although Wingfield, Nath, Freeman, et al. compared pre- and post-test scores for each of the content areas separately, unfortunately, they did not make comparisons among content areas.

Theoretical Framework

Research on efficacy beliefs emerged from the theoretical perspectives on self-efficacy, which has been thoughtfully articulated by Bandura (1977, 1997). Bandura (1997, p. 3) defines self-efficacy as "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments." In the current context, self-efficacy is the level of competency an individual *expects* to attain when teaching elementary content area material. Self-efficacy is concerned with the perceptions of competency, which depend on past experiences. As a result, efficacy beliefs may vary as a function of the personal experiences an individual had in a particular content area.

In an exhaustive review of the research on teaching efficacy, Tschannen-Moran et al. (1998) proposed a comprehensive model of how teacher efficacy judgments might be made. In the model, Tschannen-Moran et al. cogently argue that efficacy beliefs result from taking both (a) teaching task and contextual factors and (b) teacher competence into account. Thus, respondents must evaluate the *teaching task* and how effectively they can conduct that task as they account for their perceived *competence*. Importantly, Tschannen-Moran et al. (p. 233) also contend that *analysis of the teaching task* "will be more salient in shaping efficacy beliefs when teachers lack experience or when tasks are novel." As a result, preservice teachers would weight the teaching task more heavily in their assessments of teaching efficacy than would their more experienced counterparts.

Summary

Taken together, with the exception of the considerable efforts on examining EFT science and the primarily recent work on EFT mathematics, much less is known about EFT specific content areas such as reading, classroom management, and general instruction. Moreover, even less is known about whether preservice elementary teachers demonstrate differences in efficacy beliefs among elementary content areas. For example, we can all attest to the "anecdotal information" suggesting preservice elementary teachers have concerns about their ability to teach mathematics and science, but where do these two content areas stand with respect to, say, efficacy for teaching reading and other areas? In the present study, efficacy for teaching elementary content areas was examined using an instrument specifically designed to take the influence of content areas into account.

Research Problems

Based on previous research results, several hypotheses guided the research effort. First, with respect to the whole sample, it was hypothesized efficacy beliefs would vary across the five content areas. Further, it was anticipated that EFT science and EFT mathematics would be lower than efficacy beliefs for other content areas. Finally, it was hypothesized there would be several clusters, groups, of students demonstrating

differential efficacy beliefs across the five content areas. For example, it was anticipated that a group demonstrating low science efficacy beliefs would emerge, as well as a group showing low mathematics efficacy beliefs.

Method

Participants

Participants included 325 undergraduate, preservice elementary, bilingual/ESL, and early childhood education majors who were just beginning their teacher preparation coursework. These students had completed two science courses to fulfill university general studies requirements; typically an introductory biology course and either an introductory physical science, chemistry, or physics course. With respect to mathematics preparation, students had completed a general college mathematics course and a mathematics course focused on mathematics content consistent with what is taught at the elementary school level. Upon successful completion of coursework and student teaching, students participating in these programs would be eligible for a state elementary education certificate, which qualifies all of these students to teach all subjects including mathematics and science in kindergarten through sixth-grade classrooms. The mean age was 27.25 years with an $SD = 8.46$ and a range from 19–61 years. Of the participants, 305 were females and 20 were males.

Instrument

The newly developed efficacy beliefs measure was composed of items that assessed efficacy for teaching elementary school content in five areas: science, mathematics, reading, classroom management, and general instruction. A 6-point Likert-scale was employed with responses ranging from 1 = *Strongly Disagree* to 6 = *Strongly Agree*. Higher scores indicated greater efficacy. The measure was composed of 15 items and included three items from each of the following five content areas—science, mathematics, reading, classroom management, and general instruction. Illustrative items are:

1. I will teach elementary school reading successfully.

3. Generally, I will teach science effectively.

6. Even if I try hard, I will *not* teach mathematics as well as I will teach most subjects. This last item is an example of a negatively worded item. Negatively worded items were reverse scored in the computation of efficacy scores for participants.

Procedure

The participants completed the efficacy beliefs measure at an orientation meeting prior to the beginning of their coursework and field experiences in the professional teacher preparation program.

Results

Results from a principal components analysis with a promax rotation of students' responses to the efficacy instrument indicated there were four factors that accounted for 72.25% of the variance. The four factors were labeled: EFT Classroom Management/General Instruction, EFT Mathematics, EFT Science, and EFT Reading.

Based on student response patterns, participants rated efficacy for classroom management and efficacy for general instruction items in similar ways. Because the items that form these two categories were highly correlated, results from the analysis exhibited only one factor that combined items assessing efficacy for classroom management with those measuring efficacy for general instruction. Pattern coefficients for the six items of this first factor ranged from .611 to .866. EFT mathematics constituted the second factor with pattern coefficients for three items between .750 and .865. The third factor was EFT science with pattern coefficients between .351 and .946. The fourth factor was EFT reading with pattern coefficients between .330 and .965. "*[P]attern coefficients* are the weights applied to the measured variables [items] to obtain scores on the factor analysis . . . these weights are also analogous to the beta weights in multiple regression" (Thompson, 2004, p. 16). Pattern coefficients greater than .300 indicate a substantive relation between the item and the factor and thus, aid in defining the factor.

The factors were extraordinarily clear showing simple structure (i.e., high pattern coefficients for math items on the math factor and negligible coefficients of math items on the other factors, high pattern coefficients for science items on the science factor, etc.). Additionally, consistent with the guidelines advocated by Thompson (2004) structure coefficients displayed the same configuration as the pattern coefficients, supporting the previous four factor interpretation. Thus, the instrument is valid in terms of assessing efficacy for the content areas. Given the exploratory nature of the research being conducted, it was determined that all five scales would be retained in subsequent analyses of the data.

Reliability analyses were also conducted for the five efficacy scales. Cronbach's alpha reliability coefficients for EFT science, EFT mathematics, EFT reading, EFT classroom management, and EFT general classroom instruction were .82, .87, .71, .84, and .81, respectively. The reliability coefficients are substantial and attest to the reliability of the five scales.

A repeated measures analysis of variance (ANOVA) was conducted to determine whether there were differences in the mean efficacy ratings for the five content areas. Results from the ANOVA showed there were differences among the means, $F(4, 1296) = 64.65$, $p < .001$. The effect size computed using partial eta-squared was .166, which is a large effect size for a within-subjects design based on Cohen's criteria (Olejnik & Algina, 2000). Means and standard deviations for the five efficacy scales are presented in Table 1. Pairwise comparisons revealed all five means were significantly different from one another.

To examine the patterns of efficacy beliefs exhibited by individuals, all 325 participants' scores on the five efficacy beliefs were analyzed using the K-Means Cluster procedure in SPSS. Participants who demonstrate similar score profiles or patterns across the five efficacy beliefs are grouped into clusters during the cluster analysis process, which employs statistical algorithms to compose these groups. The patterns of group profiles across the five efficacy beliefs revealed six clusters of participants. Five- and seven-cluster solutions were also examined. The five-cluster solution was insufficiently detailed because it grouped too many participants together and "washed" out differences in the beliefs exhibited by individuals. The seven-cluster solution contained two extremely small clusters of two and nine participants, which made these groups too small to provide substantive meaning. The six-cluster solution allowed for sufficient detail and was readily interpretable based on the mean scores for the six cluster groups presented in Table 2.

Cluster 1 included 17 individuals, just over 5% of the sample, who demonstrated uniformly low efficacy beliefs for four of the five areas. Consistent with the hypothesized low EFT science, this cluster exhibited the lowest scores for—EFT science, 3.16 versus 4.64 for the entire sample, a difference of almost 1.50 points. In addition, of all the groups, cluster 1 had the lowest EFT reading, 4.00 as compared with 4.98 for the whole group, and second lowest EFT scores for classroom management, 4.45 versus 5.17 for the group, and general instruction 4.45 versus 5.27 for the whole sample.

Table 1
Means and Standard Deviations for the Five Teaching Efficacy Beliefs

Efficacy for Teaching	Mean	*SD*
Science	4.64	.86
Mathematics	4.82	.87
Reading	4.98	.66
Classroom management	5.17	.62
General instruction	5.27	.56

Table 2
Means for Five Teaching Efficacy Beliefs across Six Clusters

	Cluster						Mean
Efficacy for Teaching	1 (17)*	2 (55)	3 (27)	4 (42)	5 (81)	6 (103)	
Science	3.16	3.95	4.74	4.33	5.62	4.58	4.64
Mathematics	4.38	3.59	4.35	4.51	5.53	5.23	4.82
Reading	4.00	5.17	4.78	4.21	5.47	5.02	4.98
Classroom management	4.45	5.27	3.99	5.06	5.75	5.15	5.17
General instruction	4.45	5.34	4.40	5.02	5.81	5.27	5.27

* The number in parentheses indicates the number of individuals in the cluster.

Consistent with another of the hypotheses proposed for the cluster analysis, cluster 2 was composed of 55 individuals, 17% of the sample, whose profile was characterized by especially low EFT mathematics scores, 3.59 versus 4.82 for the entire sample, a difference of 1.23 points. Additionally, this group had relatively low EFT science scores, 3.95 versus 4.64, compared with the sample as a whole. For all other EFT measures, cluster 2 was unremarkable, having means just slightly above the means for the whole sample. The third cluster included 27 individuals, approximately 8% of the sample, whose efficacy belief scores were especially low on efficacy for classroom management and efficacy for general instruction, and moderately low on EFT mathematics, 3.99, 4.40, and 4.35, respectively, compared with 5.17, 5.27, and 4.82 for the entire sample.

Cluster 4 consisted of 42 individuals, approximately 13% of the sample, who were very low on EFT reading and who also exhibited slightly lower efficacy beliefs for both EFT science and EFT mathematics with scores of 4.21, 4.33, and 4.51, respectively, compared with 4.98, 4.64, and 4.82 for the whole group. The fifth cluster, consisting of 81 students, 25% of the sample, demonstrated a profile that was consistently high relative to the group as a whole. Means for cluster 5 were half a point to approximately one point higher than those for the whole group. The greatest discrepancy, relative to the whole group, for cluster 5 occurred for EFT science, which was .98 points higher than the mean for the entire sample. The sixth cluster, composed of 103 students or about 32% of the sample, demonstrated consistent scores across the five efficacy measures. For cluster 6, the EFT scores tended to be just slightly above or slightly below the mean scores for the whole sample with one exception of a moderately elevated EFT mathematics score.

To determine whether the mean *profiles* for the various clusters were different from one another, a multivariate analysis of variance (MANOVA) of the five efficacy scores for the six cluster groups was conducted. The MANOVA was statistically significant, multivariate $F(25, 1595) = 36.74$, $p < .001$. Follow-up, univariate ANOVAs were performed for each of the five efficacy measures. These ANOVAs were all statistically significant: EFT science—$F(5, 319) = 95.97$, $p < .001$; EFT math—$F(5, 319) = 113.04$, $p < .001$; EFT reading—$F(5, 319) = 52.21$, $p < .001$; EFT classroom management—$F(5, 319) = 92.98$, $p < .001$; and EFT general instruction—$F(5, 319) = 82.69$, $p < .001$. For each of the five variables, 15 Scheffe' post-hoc, pair-wise comparisons of the means were conducted to determine which clusters differed from one another. Results from these conservative Scheffe' comparisons showed 12 or 13 of the 15 pair-wise comparisons were significant for each of the five variables. Taken together, these results indicate the mean scores for the six clusters across of the five content areas were distinguishable from one another and hence they represent groups with distinct efficacy belief profiles.

Discussion

The discussion is divided into two sections. In the first section, the results from the repeated measures ANOVA are considered. Following that section, results from the cluster analysis are considered. In each section, implications for delivery of teacher preparation programs are integrated into the discussion.

Results from the repeated measures ANOVA confirm the hypothesis that EFT science and EFT mathematics are lower than efficacy beliefs about other elementary content areas. Further, these results are consistent with previous research which indicates students demonstrate concerns about their abilities to teach science and mathematics (Appleton, 2003; Mulholland & Wallace, 2000; Swars, 2005; Swars et al., 2006). Specifically, participants believed they would be least efficacious in their teaching of science, with these scores being about one-third of a point lower than the average for all five areas and almost two-thirds of a point lower than their ratings for general instruction. EFT mathematics was the second lowest score indicating participants' concerns about their abilities to teach mathematics, which is also consistent with anecdotal concerns expressed by preservice teachers and the research literature.

We can understand how variation might occur in the results if we consider how efficacy judgments are made. Tschannen-Moran et al. (1998) note there are two critical factors in making efficacy judgments: (a) an analysis of the teaching task and its context and (b) an assessment of personal strengths and weaknesses relative to the task demands. Thus, the lowest efficacy beliefs score for EFT science may result because participants assessed themselves as being less knowledgeable with respect to science (i.e., a weakness relative to the task demands) and thus judge themselves as being less able to effectively

deliver instruction in science reducing the efficacy scores for this content area.

By comparison, the high ratings for general instruction and classroom management may be accounted for by *unrealistic optimism* that was noted by Weinstein (1988) in her study of preservice teachers. In their self-ratings, Weinstein's preservice teachers demonstrated a bias indicating they would be better able to deal with management issues as well as instructional issues that arose in a classroom than would a peer and that in general "teaching would be less problematic for them than for their peers" (p. 38). Further, these high efficacy ratings for classroom management and general instruction may reflect the stage of *nonconcern* characteristic of education students prior to teaching experience (Fuller, 1969) or the relative lack of concern about classroom discipline compared with concern about tasks, impact, and knowledge of subject matter for those at the beginning of teacher preparation observed by Evans and Tribble (1986). Moreover, because these preservice teachers were just beginning their teacher preparation program, unrealistic optimism and nonconcern may generally underlie the ratings and as a result elevate the efficacy scores for classroom management and general instruction.

Nevertheless, based on the overall findings it is clear that preservice teachers assess their efficacy beliefs for teaching content areas differentially with science and mathematics receiving lower efficacy beliefs scores than other content areas. The implication for teacher preparation programs is that increasing students' competence and confidence for teaching in these areas is of considerable importance because once efficacies are established they are *not* readily changed (Tschannen-Moran et al., 1998). Thus, students who are just beginning their preparation programs are most likely to benefit from program opportunities that foster realistic development of teaching efficacy beliefs, especially in those areas where they judged themselves to be less capable.

Two ways preservice teachers can benefit from program opportunities are by observing teachers delivering effective science and/or mathematics instruction in the content areas *and* by successfully delivering instruction in the content areas. Bandura (1997) suggests that vicarious experiences, observing others, are important in developing a sense of efficacy. Therefore, providing strong teacher models throughout their preparation is important in building teaching efficacy. Additionally, effective models in science methods courses and mathematics methods courses are likely to increase efficacy for teaching in these content areas. Numerous studies have shown that increases in efficacy beliefs result when effective methods courses are offered (Moseley & Utley, 2006; Mulholland et al., 2004; Swars, Hart, Smith, Smith, & Tolar, 2007; Utley et al., 2005; Wilkins & Brand, 2004; Wingfield, Nath, Freeman, et al., 2000; Wingfield, Nath, Henry, et al., 2000). More importantly, Bandura maintains that mastery or enactive experiences based on successful teaching events are the most crucial influences that contribute to beliefs about teaching efficacy. Thus, preparation programs must be designed to provide students with ample, ongoing opportunities to engage in successful teaching experiences to promote the development of sound teaching efficacy in all content areas among prospective elementary teachers.

As hypothesized, there are several clusters of students demonstrating differential efficacy beliefs across the five content areas. For example, individuals in cluster 1 demonstrated the predicted low EFT science in combination with low scores in other areas. Moreover, individuals in cluster 2 demonstrated the hypothesized low EFT mathematics scores. In previous research, teachers who have greater efficacy (a) expended more effort in a teaching situation and persisted more readily in the face of obstacles (Gibson & Dembo, 1984); (b) used more time in organizing and planning instruction (Allinder, 1994); and (c) spent more time teaching science and allocated more time to fully develop the science concept being taught (Riggs & Jesunathadas, 1993). On the other hand, Riggs (1995) found teachers with *lower* personal science teaching efficacy spent less time teaching science, used a textbook approach, were rated as weak by site observers, and were less likely to teach science.

Taking into account this information and the current results, several questions related to instruction in science and mathematics arise. For example, would those individuals in cluster 1 who have low efficacy beliefs for teaching science spend less time teaching it? Would they engage in less planning time? Would they deliver instruction less effectively? Would they expend less effort in the science teaching situation? These same questions can be applied to cluster 2, which exhibited low efficacy beliefs for teaching mathematics; and cluster 4, which demonstrated low reading efficacy beliefs and moderately low EFT scores for science and mathematics.

Cluster 5 may be characterized as the "overly optimistic" group. All their scores are between .50 and .98 points higher than the average score for the whole group. As these preservice teachers graduate and assume teaching positions, it would be informative to determine whether they are more resilient in their teaching careers, whether they hold higher expectations of their students, whether they exert more effort in their instruction of all students in all content areas, etc. Alternatively, is this group merely exhibiting unrealistic optimism or are they metacognitively insensitive in their analyses of their efficacies to conduct instruction in these elementary content areas?

Given that efficacy beliefs develop early and are somewhat resistant to change (Tschannen-Moran et al., 1998), the implications for teacher preparation are quite compelling because preservice teachers' efficacy is more malleable since they have fewer mastery experiences (Bandura, 1997; Tschannen-Moran et al.). Based on the results from the cluster analyses, it is clear that differentiated instruction is warranted for students in teacher preparation programs. Specifically, individual students may benefit from learning additional content material or from additional pedagogical material, especially in the areas of science and mathematics. This additional material would best be delivered in science and mathematics modules that are specifically targeted to a student's needs. For example, cluster 1, which demonstrates low EFT science, may be aided by additional science instruction. On the other hand, it is obvious cluster 2 requires additional assistance when they are learning how to teach science and mathematics based on their lower efficacy beliefs in these content areas. Just as differentiated instruction benefits elementary-aged students, it is likely to benefit preservice teachers.

Finally, based on the results of the cluster analysis, it is clear that preparation programs must exhibit more flexibility in preparing teachers. In particular, adaptations of preparation programs are warranted to build on the current capabilities exhibited by program participants and further extend areas that may currently be less well developed. In such a preparation program, students would participate in individualized, supplemental modules or coursework to ensure the development of competence and confidence for teaching the subject matter areas required of elementary school teachers. Providing appropriate *live and virtual observation* opportunities for individuals with low efficacy beliefs in a content area would be one approach to increasing low efficacy beliefs. For example, those with low EFT science may benefit from virtual observations using videos and internet-based materials. Moreover, careful consideration must be given to placement of preservice teachers with mentors who can provide appropriate modeling of effective teaching. Finally, designing appropriate, increasingly responsible opportunities that provide mastery experiences for preservice teachers in teaching elementary content, especially in science and mathematics, is another approach that will foster the development of appropriate efficacy beliefs.

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Evaluating Mathematics Achievement of Middle School Students in a Looping Environment

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Looping, a school structure where students remain with one group of teachers for two or more school years, is used by middle schools to meet the diverse needs of young adolescents. However, little research exists on how looping effects the academic performance of students. This study was designed to determine if looping influenced middle school students' mathematical academic achievement. Student scores on the Mississippi Curriculum Test (MCT) were compared between sixth and eighth grade years for 69 students who looped during the seventh and eighth grades with a group of 137 students who did not loop. Looping students achieved statistically significantly greater growth on the MCT than their nonlooping counterparts between sixth and eighth grades. Further, the data were disaggregated by gender, ethnicity, and socioeconomic status. Findings indicate that looping may academically reengage students during the middle school years. Advantages and disadvantages of looping at the middle grades are discussed.

Middle school mathematics could be referred to as *math in the middle*. For example, students are ability-tracked, often for the first time. Mathematical concepts become increasingly abstract and complex, demanding a thorough understanding of mathematics learned in earlier grades (Carraher & Schliemann, 2007; Kieran, 2007). Teaching styles and classroom and school day organization begin to vary. Teachers may be secondary-trained content specialists, middle-level specialists with a mathematical content emphasis, or elementary educators with varying levels of mathematical content knowledge. Further, teachers perpetuate the beliefs that males are simply better at mathematics than females as seen in teacher behavior (Good & Brophy, 2007), despite evidence from Trends in International Math and Science Study, TIMSS, (National Center for Education Statistics, 2003) along with other research (Fennema & Leder, 1998; Hyde, 1990; Noddings, 1993), which indicates there are no significant differences between males' and females' abilities in mathematics and/or sciences. Young adolescents need well-prepared teachers in middle schools who can bridge the transitions from elementary school mathematics to increasingly abstract middle school courses, break perceived barriers to access mathematics, and keep students motivated and excited about learning mathematics.

Recent research suggests motivational factors such as students' intellectual support by teachers and peers are extremely important in the achievement of mathematics (National Mathematics Advisory Panel, 2008; Shores & Shannon, 2007). Achievement gaps for minority students in mathematics, while trending downward, is still greater than 30 points between African American and Caucasian students and slightly less than 30 points between Hispanic and Caucasian students in eighth grade (National Center for Education Statistics, 2008). When minority status is combined with poverty, the need for a supportive learning environment is essential (Payne, 2005). Young adolescents need organizational structures in middle schools that may reduce the effect of poverty on academic achievement. Research has shown that the greater the poverty level of a school, as indicated by the number

of students receiving free or reduced lunch, the lower the overall academic achievement (Brown, Roney, & Anfara, 2003; Mertens & Flowers, 2003).

Middle-level education is challenging for both teachers and students. Students are deciding what their attitudes are about mathematics, education, and even careers. Increased student achievement, participation and attendance in school, and reduced disciplinary issues are all attributed to the development of a long-term teacher-student relationship (George & Lounsbury, 2000). Looping, as an organizational structure, supports the development of this type of relationship. Further, looping may provide an environment that fosters student achievement in middle school mathematics.

Background

At the time of its inception, the idea behind the middle school was to create a school for older children who were *in the middle* (Alexander, 1995) that needed a developmentally appropriate and responsive learning environment. The students who were *in the middle* were not quite ready for the challenging aspects of high school but were definitely able to work more independently than elementary school students were. The resulting middle school was designed to feature several educational components that foster all areas of young adolescent development: physical, intellectual, emotional, social, and moral. The most common elements of the middle school concept that best meet the needs of young adolescents are interdisciplinary teams, advisory, transition and exploratory programs, and teaching a curriculum that employs varied instructional practices and is "relevant, challenging, exploratory, and integrated" (National Middle School Association, 2003). Teacher teams with common planning time that meet regularly to discuss the needs of their students are also more responsive to students' academic and affective needs (George & Alexander, 2003; Kellough & Kellough, 2003; Powell, 2005). Although several decades have passed since this original vision was unveiled, the ideas for what middle school should be have not changed.

In addition to the academic emphasis of schooling and the pressures of standardized assessments, middle school teachers and administrators have to deal with the ever-changing needs of adolescents. Young adolescents are experiencing a vast amount of change at this time in their lives. Physical and intellectual development occurs concurrently with each greatly influencing the other (Powell, 2005). How a young adolescent feels physically affects every other aspect of his or her life. Added to these basic physiological changes is the need to fit-in and the desire to belong—the young adolescent lives in a tumultuous world that is constantly evolving. Young adolescents need teachers who understand their development and are knowledgeable about the world in which they live (Jackson & Davis, 2000). This critical time in their lives emphasizes the need for stability and structure. Young adolescents require a learning environment that supports them so they are able to be successful in school. Looping is a structure that allows teachers to blend increasingly complex content and specialized subject matter with a nurturing learning environment (Kellough & Kellough, 2003; Powell).

Advantages of Looping

Looping is an organizational structure that keeps students and teachers together for two or more school years. Comer (2001) posited that significant relationships must be established between teachers and students for significant learning to occur. The looping environment creates an atmosphere where young adolescents are able to take risks with learning because significant relationships are developed between the teacher and students. This established relationship enables students to achieve success in a variety of areas. As noted by Jackson and Davis (2000), every young adolescent needs the opportunity to experience success in school. Looping is a structure that provides this opportunity. Although most of the reported benefits of looping do not directly address academic achievement, the context for improved academic success is created. Likewise, students in mathematics classrooms need to be encouraged to take risks. Increasing cognitive demands in mathematics are dependent on students conjecturing about their work and making connections to concepts previously learned. Being in a classroom that supports and even encourages risk-taking is imperative for mathematical growth (NCTM, 2000).

Looping provides teachers time to get to know their students' strengths and weaknesses (Crosby, 1998; Elliot, 1998; Forsten, Grant, Johnson & Richardson, 1997), track students' long-term progress (Forsten, Grant & Richardson, 1999), and improve instructional planning (George & Lounsbury, 2000; George & Shewey, 1997; Manning & Bucher, 2001). The extended time also enhances the teacher's role as a "guide and facilitator of learning" (Kasak, 2004, p. 243). Long-term relationships facilitate the

development of effective instructional approaches that meet students' specific needs (George & Shewey, 1997; McLaughlin & Doda, 1997). This environment is needed for students as their mathematical understandings develop. Sleep and Ball (2007), in their research on mathematics' teachers, described the impreciseness of students' discourse about mathematics. They further emphasized the need for teachers that can listen and interpret their students' mathematical statements. Teachers who have long-term relationships with students develop insights into the ways their students think and talk, helping interpret classroom discourse.

Looping-developed relationships lead to continuity, generating better learning environments and positive relationships between teachers, students, and parents. Jackson and Davis (2000) posit that time provided by looping allows students and parents to develop healthy attachments to teachers. The mathematical field gains a decided benefit. Specifically, females and underrepresented groups need support as they develop their mathematical interests. Despite the efforts of national funding agencies to narrow the gap between males' and females' interests in mathematics and related STEM fields, females still lag behind males. Since career exploration begins in middle school, having environments that support female or minority interests is important. Positive teacher-student relationships enhance this process. Numerous studies support this idea (e.g., American Association of University Women, 2004; Darke, Clewell, & Sevo, 2002; Dentith, 2008; McCullough, 2003).

A great deal of time is spent each school year in the "getting to know you" process. Time normally dedicated to this relationship building is reduced when looping. George and Lounsbury (2000) and George and Shewey (1997) studied long-term teacher–student and teacher–parent relationships. They found that all looping participants agreed a greater sense of community developed as time progressed. Improved relationships between teachers, students, and parents lead to increased satisfaction in the educational experience (Forsten et al., 1999). Each group did not have to experience normal adjustment periods that occur every school year. Further, time is saved by already understanding students' knowledge levels (Crosby, 1998; Darling-Hammond, 1997); this is particularly helpful for students facing academic or social challenges (Forsten et al., 1997). With increasingly complex and abstract concepts being presented in middle-level mathematics courses, the gained instructional time provided by looping gives teachers additional opportunities to assess their students' skills and understandings.

Disadvantages of Looping

While the advantages of looping are notable, disadvantages do exist. The primary concern associated with looping is the teacher. Veteran teachers, who have more experience with classroom management and varied instructional strategies, tend to experience greater success when looping than beginning teachers do (Simel, 1998). Seasoned teachers have larger "bags of tricks" and tend not to run out of new and innovative ideas for teaching, building rapport with students and parents, and managing the classroom. Further, all teachers and administrators associated with looping need to be educated about the structure and complexity of it. Proper training and implementation is necessary so that looping teachers and administrators understand all of the components of looping and are aware of the investment that will be made. Additionally, administrators need to understand the intricacies of looping and realize it does create a positive learning environment, but looping is not necessarily a structure that will meet the learning needs of students with disabilities, second language learners, or other students with additional social or academic needs (Forsten et al., 1997; McAteer, 2001; Simel).

Parental concerns about looping exist as well. Parents of looping students tend to worry that their child will be taught by an ineffective teacher for two or more years and may feel that their child is "stuck." In addition, parents, students, and teachers might experience difficulty cultivating the long-term relationship associated with looping which might reduce its positive impact (Nichols & Nichols, 2002; Simel, 1998). Finally, students who transition into and out of the looping cycle might experience feelings of being an "outcast" either in the looping classroom or in their new school (Simel). Looping creates cohesiveness among all people involved and being a member of a tightly knit group may be difficult. Likewise, leaving such a group can have a profound impact on a student. Therefore, looping works best when students begin and end the loop together; yet this does not always occur given the transient nature of society. Everyone involved in the looping cycle needs to communicate effectively with the other, as relationship building is the backbone of the looping process.

Purpose of the Research

The majority of research about looping tends to focus on the elementary school and be qualitative in nature. Therefore, the purpose of this research was twofold. The primary objective was to determine if middle grades students who looped performed better on the mathematics portion of the Mississippi Curriculum Test (MCT) than did their nonlooping peers. Expanding on that notion, the researchers were interested in finding connections between gender, ethnic group, and socioeconomic status and looping, and if those connections impacted MCT performance. The secondary reason to conduct the research was to contribute to the limited research base regarding middle grades looping.

Methods

Setting

The Middle School. This research occurred in a middle school located in rural east central Mississippi. The middle school is the only school in the district serving grades seven and eight. Sixth grade students are housed at a separate stand-alone campus. In the mid-1990s, both the sixth grade school and the middle school implemented elements of the middle school philosophy, including interdisciplinary teaming (i.e., mathematics, language arts, science, and social studies teachers collaboratively working with the same group of students), flexible scheduling (i.e., interdisciplinary teams' ability to manipulate their daily schedule to meet instructional goals), (George & Alexander, 2003), and common planning time (i.e., a specified time set aside each day for interdisciplinary teams to meet and discuss ideas, issues, and student needs) (Mertens, Roney, Anfara, & Caskey, 2007). The district has consistently scored near or above the state average on the statewide criterion referenced MCT.

The average enrollment at the middle school is 650 students. The teacher to student ratio is approximately 1:30. About 65% of the district's students qualify for free or reduced lunch. The district has a highly transient population due to both its proximity to a major university and the mobility of its low socioeconomic population.

School Context. All students were placed on interdisciplinary teams. To maintain equity and stability within core teams (i.e., language arts, science, social studies, and mathematics), school administration assigned teachers to teams so that each team had equal ratios of experienced and less-experienced teachers. Time was provided to teachers for individual planning as well as for common planning time. To ensure the same content was taught in all classrooms, members of the faculty met bi-monthly within subject area departments to focus on curriculum maps. Curriculum maps are living documents which are teacher-created, used to guide content and assessments throughout the school year (Hayes Jacobs, 2004). These maps were constantly revised to meet the academic needs of students. Common assessments were also given to students each nine-week grading period, ensuring that common instruction occurred.

Sample

This study tracked the mathematics achievement of 206 students during their seventh and eighth grade years. The students' sixth grade mathematics MCT scores were used as baseline data. The treatment group (looping team) consisted of 69 students who looped (i.e., remained with the same team of teachers) during only grades 7 and 8; the comparison group (nonlooping teams) consisted of 137 students who did not loop during grades 7 and 8. The looping team consisted of 35 females and 34 males. The nonlooping teams were composed of 82 females and 55 males. Overall, there were 124 African American students, 78 Caucasians and 4 students of "other" races. The looping team consisted of 36 African Americans, 31 Caucasians and 2 other race students. The nonlooping teams consisted of 88 African Americans, 47 Caucasians and 2 other race students. Socioeconomic status (SES) was determined by qualification for free or reduced lunch. The looping team had 51% of students identified as low SES while 63% of the nonlooping teams' students were classified as low SES.

This school district has a history of allowing parent choice with regard to teacher selection. Approximately, 50% of the parents participate in this process at the middle school (Principal, personal communication, January 8, 2009). During the time of this study, parents were given the opportunity to select their child's teaching team with the knowledge that one particular team would loop. However, parents were as likely to select looping or nonlooping teams as the overall deciding factor was the teacher, not organization. Over the years, the school district has refined a process to disseminate students among teams based on parent choice, gender, ethnicity, and academic ability. Looping had been used previously in this district in lower elementary grades. This study coincides with the initial implementation of looping at the middle

school. For the purposes of this study, students who were not promoted to a subsequent grade and students in special education who did not participate in statewide testing were excluded. MCT data for these two specific groups of students were not available, as such; they could not be included in the analysis.

Five mathematics teachers participated in the study. The looping teacher had a Bachelors of Science in Secondary Mathematics Education and a Masters of Arts in Elementary Education. This teacher had 10 years of teaching experience. The remaining four teachers taught either seventh or eight grade mathematics. One seventh-grade teacher had a Bachelors of Science in Mathematics and subsequently acquired teaching certification through an Alternate Route program; the other teacher had Bachelors of Science in Elementary Education. These teachers had 9 and 2 years of experience, respectively. Both eighth grade teachers had secondary certification and had earned Masters of Science in Curriculum and Instruction. The eighth grade teachers had more than 10 years of experience each.

Instrumentation

The MCT is a state designed criterion-referenced assessment that is given to all students enrolled in the public schools of Mississippi in grades 3 through 8 (Mississippi Department of Education, 2005). The Mississippi State Assessment Office has developed the series of assessments to measure student mastery of the state created curriculum. State-level curriculum specialists and professors of education, with the assistance of local teachers, reevaluate the curriculum framework every five years. The curriculum and assessments were created to meet the requirements set forth in the Elementary and Secondary Education Act (PL 89-10, 20 U. S. C.§ 6301 et seq.). Subsequently, state officials increased the number of grades assessed in response to specific mandates in *No Child Left Behind*.

The MCT test has three parts: reading, language, and mathematics. The MCT is a nontimed test given to the students on three consecutive days during the first week of May each year. The assessment used in this study is the mathematics component of the MCT, which is given on the third day of the testing cycle.

Procedure

The researchers chose a causal-comparative design to examine the effect of looping on student achievement in mathematics. The nature of this study drove the decision to choose this *ex post facto* approach. Participants were chosen from all students enrolled in the middle school from 2003–2005. Criteria for participation were the student was (1) enrolled in the middle school from 2003–2005; (2) was not retained for any of the years of the study; and (3) participated in the MCT each year. Researchers formed two groups of participants. Group one, the treatment group, consisted of students who looped in grades 7 and 8. Group two, the comparison group, consisted of students who did not loop. Descriptive statistics and MCT scores were collected on all participants. Finally, the effect size was calculated using Cohen's *d*.

Results

Data were collected to determine if middle school students taught by a looping team of teachers achieved higher mathematics scores on the MCT than middle school students who were not taught on a looping team. Mathematics MCT scores from 2003–2005 comprise this data set. Prior to performing the analysis to determine the effect of looping, it was necessary to ensure that the scores of the looping team and nonlooping teams were not statistically different in their initial placement in the seventh grade. Sixth grade MCT scores were used as baseline data. A one-way analysis of variance (ANOVA) was used to determine whether student scores were equitable. Next, a second ANOVA was completed to compare test scores and student growth for the teams. In addition, ANOVAs were performed to determine the statistical significance of gender, socioeconomic status, or ethnicity on scores and student growth (Gravetter & Wallnau, 2000; Howell, 2002). All data were evaluated using alpha level of significance set at .05. Finally, Cohen's *d* was determined to be $d = .40$ for this study, a small to moderate effect size.

Although the school district has a process for equally distributing students by gender, socioeconomic status, and ethnicity, the research team used sixth grade MCT mathematics scores to compare looping and nonlooping teams to verify team equality. Sixth grade MCT math scores averaged 586.87 for students on the looping team and 570.61 for students on nonlooping teams (see Table 1). The sixth grade math scores were not statistically significantly different between the two groups ($p = .054$) indicating that the looping and nonlooping groups were relatively evenly distributed.

Team Results

The average seventh grade MCT mathematics scores on the looping team were 612.42 compared with 586.39 for the nonlooping teams. The difference in

Table 1
Mississippi Curriculum Test Mathematics Results, Looping versus Nonlooping

	Sample *N*	Mean Score *M*			Change in Mean Score Δ		
Treatments		6th	7th	8th	6th–7th	7th–8th	6th–8th
Looping	69	586.870	612.420	621.970	25.550	9.550	35.100
Nonlooping	137	570.610	586.390	595.480	15.780	9.090	24.870
F-test (*p*)		.054	.002	.002	.041	.921	S.043

Table 2
Aggregated Mississippi Curriculum Test Mathematics Results: All Participants, Schools, and State

	Mean Score *M*			Change in Mean Score Δ		
Treatments	6th	7th	8th	6th–7th	7th–8th	6th–8th
School*	567.5	584.8	589.6	17.3	4.8	22.1
State	556.9	571.5	588.5	14.6	17.0	31.6

* Includes all students enrolled in the middle school.

mathematics scores between the teams in seventh grade was significant ($p = .002$). In the eighth grade, looping students averaged 621.97 compared with 595.48 for nonlooping students ($p = .002$). Thus, in seventh and eight grades, students in the looping classes scored higher on the mathematics portion of the MCT (see Table 1). Table 2 shows MCT scores as provided by the state for all tested students during the study. A comparison of looping team data to overall school data documents that the growth of looping participants from seventh to eighth grade was almost twice that of the schools' growth. Therefore, these results indicate that students in looping mathematics courses outperformed their counterparts in the nonlooping mathematics courses. Over the 2 years of the study, the looping students increased their mathematics MCT scores by an average of 35.10 points, whereas the nonlooping students increased their scores by an average of 24.87 points. This is statistically significant ($p = .043$). Also, a statistically significant difference in growth from sixth to seventh grade ($p = .041$), but not from seventh to eighth grade ($p = .921$) was found.

Gender

Females. There was no significant difference in the sixth grade MCT mathematics scores between the females who looped and those who did not loop, $p = .508$ (see Table 3). This indicates that the ability of the female students were evenly distributed across the looping ($M = 580.14$) and nonlooping teams ($M = 573.42$). The looping female students increased their MCT mathematics scores by 36.71 points, in comparison to 21.76 points for the nonlooping female students. The MCT seventh grade scores for looping female students increased 24.17 points compared to the 10.74 point increase for nonlooping females from sixth to eighth grade. The females who looped showed an increase of 12.54 points in eighth grade while the nonlooping females improved 11.01 points. This difference was not statistically significant ($p = .797$). However, overall growth from sixth to eighth grade for females was statistically significant ($F[1,115] = 5.584$, $p = .02$). During the seventh grade year, the female students on the looping and nonlooping teams averaged 604.31 and 584.16, respectively. The difference in scores between treatment and comparison was significant ($p = .044$). During the eighth grade year, female students who looped averaged 616.86 compared with 595.17 for nonlooping female students. There was no significant difference in scores between eighth grade looping and nonlooping females ($p = .051$).

Males. There was no significant difference in the sixth grade MCT mathematics scores between the males who looped and those who did not loop, $p = .56$ (see Table 3). This indicates that the ability of the male

Table 3
Mississippi Curriculum Test Mathematics Results by Gender

	Sample *N*	Mean Score *M*			Change in Mean Score Δ		
Treatments		6th	7th	8th	6th–7th	7th–8th	6th–8th
Female							
Looping	35	580.14	604.31	616.86	24.17	12.54	36.71
Nonlooping	82	573.42	584.16	595.17	10.74	11.01	21.76
F-test (*p*)		.51	.04	.05	.04	.80	.02
Male							
Looping	34	593.79	620.77	627.24	26.97	6.47	33.44
Nonlooping	55	566.42	589.71	595.93	23.29	6.22	29.51
F-test (*p*)		.06	.03	.02	.63	.61	.97

students were evenly distributed across the looping (M = 593.79) and nonlooping teams (M = 566.42). The seventh grade looping males mean scores were 620.77 in comparison to the nonlooping males means score of 589.71. The scores were found to be statistically significantly different ($F[1,87] = 3.766$, $p = .025$). In eighth grade, the looping males scored 627.24 in comparison to 595.93 for the nonlooping males. This difference was also statistically significant ($F[1,87] = 5.506$, $p = .021$).

There were statistically significant differences in mean scores between looping and nonlooping males. In seventh grade, the looping males had a mean score of 620.77 and nonlooping males had a mean score of 589.71, which was statistically significantly different ($p = .025$). Similarly, in eighth grade, the mean score for looping males was 627.24 and 595.93 for nonlooping males. This difference in mean scores was also statistically significantly different ($p = .021$). However, there were no statistically significant differences in growth over the two-year period as measured by change in MCT scores ($F[1,87] = .235$, $p = .629$). The looping males mean scores increased by 33.44 points, while the nonlooping males showed an increase of 29.51 points between sixth and eighth grades. Results are similar for differences in growth from the sixth to seventh and seventh to eighth grade years (see Table 3).

Ethnicity

African American and Caucasian looping students made greater gains over the two-year looping period than did their nonlooping peers. The African American students on the looping team gained 32.03 points in comparison to 23.96 points for the nonlooping African American students during the seventh and eighth grades. Total growth for looping Caucasian students was 36.74 points in comparison to 26.89 points for the nonlooping Caucasian students. Data analyzed for comparison between African American and Caucasian students were not statistically significant. During the study period, four students were classified as "other." Given this small N, they were removed from the sample (see Table 4).

Socioeconomic Status

Low socioeconomic (SES) students in both the looping and nonlooping groups scored significantly lower than the other students in their looping or nonlooping group, respectively. Low SES looping students began the seventh grade with their mean score 14.82 points below the mean scores of their low SES nonlooping peers. Growth occurred each year for low SES looping and nonlooping students. The amount of growth was not statically significant between low SES looping and nonlooping or within the looping group between the low SES group and other students. However, the looping students narrowed the gap between the mean scores of the low SES looping students and the low SES nonlooping students to 3.66 points (see Table 5).

Discussion

The purpose of this study was to examine the effect looping had on mathematics' achievement for seventh

Table 4
Mississippi Curriculum Test Mathematics Results by Ethnicity

	Sample *N*	Mean Score *M*			Change in Mean Score Δ		
Treatments		6th	7th	8th	6th–7th	7th–8th	6th–8th
African American							
Looping	36	555.11	573.00	587.14	17.89	14.14	32.03
Nonlooping	88	559.75	575.56	583.70	15.81	8.15	23.96
F-test (*p*)		.65	.79	.73	.73	.22	.17
Caucasian							
Looping	31	620.03	653.58	656.77	35.55	3.19	36.74
Nonlooping	47	589.98	573.00	616.87	15.19	11.70	26.89
F-test (*p*)		.02	.00	.00	.03	.37	.30

Table 5
Mississippi Curriculum Test Mathematics Results by Free/Reduced Lunch Status

	Sample *N*	Mean Score *M*			Change in Mean Score Δ		
Treatments		6th	7th	8th	6th–7th	7th–8th	6th–8th
Receiving Free/ Reduced Lunch							
Looping	35	545.40	567.89	579.11	22.49	11.23	33.71
Nonlooping	86	560.22	573.02	582.77	12.80	9.74	22.55
F-test (*p*)		.14	.57	.70	.12	.75	.07
Not Receiving Free/Reduced Lunch							
Looping	34	629.56	658.27	666.09	28.71	7.82	36.74
Nonlooping	51	588.12	608.92	616.90	20.80	7.98	26.89
F-test (*p*)		.00	.00	.00	.31	1.00	.38

and eighth grade students at one middle school. Given that the research base, both quantitative and qualitative, to support looping at the middle level is minimal, the researchers' secondary purpose was to contribute to this literature. Therefore, the progress of students in both looping and nonlooping teams was tracked using the mathematics portion of the state-wide criterion referenced test, the Mississippi Curriculum Test or MCT, during their seventh and eighth grade years. Scores on the MCT were compared generally and then across gender, ethnicity and socioeconomic status. The overall mathematics MCT mean score for each group was used as one data point. A second measure, growth in academic achievement as indicated by change in mathematics MCT scores, provides another method for analyzing the results of this study. The overall scores for both seventh and eighth graders on the looping team were statistically significantly higher than for students who did not loop. George and Shewey's (1997) and McLaughlin and Doda's (1997) work found that the looping environment fosters the development of long-term teacher–student

relationships that leads to increased academic achievement. The results from this study support this finding with the overall scores of the looping students being significantly higher in both academic years. Despite the relatively small effect size, this study indicates there are significant interactions between mathematics and looping that need to be considered.

Comparisons among gender groups yielded interesting findings. The school intentionally distributed females and males evenly across the looping and nonlooping teams. Data indicated the performance levels on the MCT were also evenly distributed by gender. Despite the even distribution, females on the looping team scored statistically significantly higher on the MCT than their nonlooping counterparts in seventh grade. Further, females on the looping team showed statistically significant growth in their mathematics MCT scores from sixth to seventh and from sixth to eighth grade. Data for males also showed statistically significant differences in overall mathematics MCT scores in seventh and eighth grades. However, the growth for males was not significant. In other words, while looping males scored higher on the MCT, the growth from year to year was not significantly greater than their nonlooping counterparts. These findings may suggest that adolescent females tend to flourish when affect, a key component of looping, is found in their learning environment. Success in an academic area is a critical component in remaining interested in that particular area. As previously noted, students' intellectual support fostered in a nurturing learning environment are essential motivational sources in mathematics (National Mathematics Advisory Panel, 2008; Shores & Shannon, 2007). Our initial findings suggest that the looping environment supported females' mathematical growth and increased their mathematical competence; as a result, females might sustain interest in mathematics.

Over 65% of the school qualifies for free and/or reduced lunch. Because so many students are classified as low SES, the school did not use this criterion in placing students on looping or nonlooping teams. However, the researchers were interested in tracking the performance of this group. Data indicated that initially low SES students on the nonlooping teams had higher overall scores on the MCT (14.82 points higher). The low SES students on the nonlooping teams maintained the higher MCT scores over research years. Nonetheless, the low SES students on the looping team narrowed the gap on their MCT scores by 11.16 points. Researchers have found that the higher the level of poverty in a school, the lower the academic achievement is for all groups of students (Brown et al., 2003; Mertens & Flowers, 2003). The findings of this study support the belief that looping may create an environment that diminishes the influences of SES on academic achievement.

Perhaps the most striking finding from this research study is that all looping students showed greater gains in the first year of the looping cycle—not in the second. In seventh and eighth grades years, looping students had a larger increase in their academic achievement. The growth exhibited by looping students between sixth and seventh and between sixth and eighth grades was statistically significantly higher than those of the students in nonlooping teams. However, the growth from seventh to eighth grade was not statistically significant between the two groups. This finding may indicate that the initial investment made by teachers, students, and parents into the educational relationship is more profound in the first year of looping when everyone involved understands the long-term commitment. Consequently, teachers and students might exert more effort to develop a true community of learners which results in maximizing student performance in year one while maintaining academic achievement in year two. Further, this finding may suggest that students regain their academic interest and commitment to even challenging content areas, like mathematics, when they realize that their teachers have a vested interest in their academic well-being.

The work of George and Lounsbury (2000), George and Shewey (1997), and Jackson and Davis (2000) is built around the notion that middle school curriculum should be "relevant, challenging, exploratory, and integrated" (National Middle School Association, 2003). Mathematics educators share a similar vision for mathematics' classrooms. Each of the principles in Principles and Standards in School Mathematics (National Council of Teachers of Mathematics, 2000) can be connected back to the middle school tenets. Therefore, it is not surprising that the mathematical achievement of looping students was better than the achievement of their counterparts in traditional middle school classrooms. This study further supports the idea that motivation and intellectual support is a key component of success for both females and low SES groups of students (Kober, 2001; Shores & Shannon, 2007). Finally, STEM research suggests females self-

select out of STEM career fields in the middle grades, even though their mathematics performance is on-level with males. With the added intellectual and emotional support provided in a looping environment, females may find the desire to continue in traditionally male dominated fields.

Limitations

While the findings of this research study are intriguing, certain limitations to the study exist. First, this study was conducted in one southern school with a relatively small sample size. Future research would need to include multiple schools in both urban and rural settings. This need for further research is also indicated by the relatively small effect size. While the effect size is small, this may indicate there is importance in the interaction between looping and performance (Abelson, 1985). Also, investigating multiple looping teams in the same school should be considered to expand this research. A second limitation is that this study had only one mathematics teacher who taught in the looping environment. The current study did not allow for comparisons among this teachers pervious classes and the researched class, as historical data was unavailable. Further quantitative research into teacher effect and looping is warranted for all subject areas, not only mathematics.

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Exploring the Link between Reformed Teaching Practices and Pupil Learning in Elementary School Mathematics

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This study examined the classroom practices of beginning elementary school teachers' instruction of mathematics and how it connected to their pupils' learning. The Reformed Teaching Observation Protocol (RTOP) was used to measure the extent to which beginning teachers used reformed teaching practices. As a measure of pupil learning, we utilized assessment scores specific to the mathematics unit observed and correlated them with teachers' RTOP scores. We found that beginning teachers who implemented reformed teaching practices tended to have pupils who scored higher on the district mathematics test with a statistically significant correlation of 0.56 ($p < .05$). Implications of these findings and others are discussed in terms of using the RTOP to improve practice at the elementary school level and for future school-based research.

Recently, the National Mathematics Advisory Panel (NMP, 2008) issued *Foundations for Success*, a report recommending improvements in mathematics education for K-12 students. In this report, it was apparent that the NMP found the results of research on many mathematics education topics "inconclusive," primarily due to a deficiency in what was counted as valid "scientific" research. In particular, the panel found that there was no evidence to support either student-centered or teacher-directed instructional practices or their subsequent relationships to pupil learning. These findings notwithstanding, efforts by the National Council of Teachers of Mathematics (NCTM) and the National Science Foundation (NSF) continue to espouse reformed teaching practices, a student-centered approach, where instruction is focused on helping students gain conceptual understanding of mathematical content through problem solving rather than instruction where students solely memorize procedures without being able to explain the mathematical process. Part of the controversy about reformed teaching practices is ambiguity about what reformed teaching actually looks like in practice and whether or not this kind of teaching can be measured and linked to pupils' learning outcomes.

Several NSF-funded studies examining reformed teaching in mathematics have compared the use of "reformed" curricula with non-reformed, or "traditional," curricula. In these studies, reformed teaching was found to be positively related to pupil achievement, with pupils of teachers who used reformed teaching practices significantly outperforming pupils who used more traditional methods (ARC Center, 2003; Boaler, 2001; Klein et al., 2000; Senk & Thompson, 2003). However, in these curricula-related studies, it was assumed that teachers using "reformed" curricula were enacting reformed teaching, and rarely were teaching practices analyzed. In another study, mathematics and science teachers who were prepared by the Collaboratives for Excellence in Teacher Preparation program (CETP) to teach using reformed teaching practices were compared with teachers who were not prepared through CETP (Huffman, Thomas, & Lawrenz, 2008). An NSF-sponsored initiative, CETP is one of the few programs that specifically targets preservice teacher (PT) preparation to improve

the pedagogical skills and content knowledge of future mathematics and science teachers. In this CETP study, pupils' attitudes toward reformed teaching practices were also examined. Although CETP mathematics teachers were found to use slightly more reformed teaching practices in the classroom, the pupils in these studies preferred non-CETP teachers, indicating that pupils preferred traditional teaching styles in mathematics. A limitation to this research and most studies on reformed teaching is that they frequently examine teaching by administering surveys and do not document actual classroom teaching practices. This has only added to the criticism of reformed teaching and the uncertainty of its definition (Schoenfeld, 2004). To make substantial claims about teaching practices, it is imperative that reliable instruments be used to examine observable classroom teaching practices and the degree to which these practices are consistent with "reformed" teaching.

For the purposes of the study described in this article, we are operating under NCTM's (2000) view of reformed teaching, which emphasizes conceptual understandings of mathematics concepts that connects prior knowledge with new experiences through active inquiry-based learning that is socially constructed and student centered. In contrast, traditional methods of teaching present mathematics as a static collection of facts, rules, and procedures to be passively learned by practice, memorization, and teacher-directed drill (Romberg, 1992). NCTM's description of reformed practices is consistent with that used in the development of the Reformed Teaching Observation Protocol (RTOP), defined as "student and teacher empowerment, development of critical thinking, and a culture that supports change . . . a movement away from the traditional didactic practice toward constructivism" (Sawada et al., 2002, p. 246). The developers of the RTOP utilized NCTM and other professional organizations' mathematics standards for its development.

In teacher preparation programs, preservice teachers who are taught reformed teaching practices are learning to teach mathematics in a way that is completely different from the way they were taught it as students (Ball, 1989; Lortie, 1975). When in their own classrooms, reformed teaching practices in mathematics can be challenging for teachers. Studies have found that beginning teachers, in particular, have difficulty teaching in a reformed manner (Ebby, 2000; Hart, 2001). Although they may have been prepared to adopt a reformed teaching practice during their preservice years, the school context of their first year plays an influential role on beginning teachers (Warfield, Wood, & Lehman, 2005). That context may or may not be supportive of reformed teaching. One clear recommendation from the NMP was the need to prepare teachers of mathematics at the elementary school level with deeper levels of mathematical content knowledge (Hill, Ball, & Schilling, 2008), as they rarely have extensive mathematical knowledge. With increasing demands for change in mathematics education, it is important that research on mathematics teaching documents the ways in which teacher education programs prepare their preservice teachers (Robinson & Adkins, 2002), how these preservice teachers practice what they were taught as beginning teachers, and what their pupils learn as a result of their teaching.

This study used the RTOP to measure the extent to which 22 beginning elementary school teachers who were teaching mathematics used reformed teaching practices. As a measure of pupil learning, we utilized pre- and post-assessment scores specific to the mathematics unit observed. Specifically, we sought to investigate the following two research questions:

1. To what extent do twenty-two beginning elementary school teachers implement reformed teaching practices in mathematics, as measured by the RTOP?
2. What is the relationship between these beginning elementary school teachers' level of reformed teaching practices and their pupils' learning in mathematics?

In the next section, we present the relevant literature examining teacher preparation for reformed teaching practices in elementary school mathematics, as well as studies examining the effectiveness of teacher education and the links among teacher preparation, teacher practices, and its impacts on pupil achievement. We then provide the context within which this study was conducted, the design of the study, and information on the RTOP and mathematics assessment measures. The results section presents inter-rater reliabilities, the RTOP scores, pre–post mathematics assessment gains, and the correlations between the RTOP and mathematics scores. We conclude with the implications of the role of teacher education in preparing elementary school teachers to use a reformed teaching approach and how it fits into this era of accountability. Finally, limitations of the research design and recommendations for future research are discussed.

Literature Review

In this review, we provide a brief summary of empirical studies that have examined the role of teacher education in preparing teachers for a reformed practice, reformed teaching practices in mathematics, and how reformed teaching influences pupil learning. The framework for this literature review is based on the Wideen, Mayer-Smith, and Moon's (1998) analysis of various aspects of learning to teach. In their review, they focus on three areas: teachers' beliefs, the role of teacher education, and the first years of teaching. Taking these aspects into consideration, we concentrate our brief review on studies examining reformed teaching practice in mathematics. The studies include discussions on teachers' beliefs about teaching and learning mathematics, and the role of teacher preparation that espouses a reformed teaching practice.

In 2007, Lawrenz, Huffman, and Gravely attempted to examine the links among teacher preparation, reformed teaching practice, and pupil experiences by comparing whether there were differences between teachers in CETP and non-CETP teachers. They surveyed university faculty, K-12 teachers and pupils, and observed K-12 classrooms to examine whether differences existed. In general, CETP teachers reported having more experiences with reformed teaching practices in the coursework and field placements than non-CETP teachers. Results also indicated a significant difference in the classroom practices with CETP teachers reflecting a more reformed teaching practice than non-CETP teachers, as indicated by the observations and pupil surveys. This large-scale study was thorough and explicit in its methodology; however, it lacked the very important connection between reformed teaching practice and pupil learning that is needed in the field.

Along similar lines, Ebby (2000) qualitatively explored how PTs learn to teach mathematics differently by using case studies to illustrate how three preservice elementary teachers made sense of their methods course and field experiences during a one-year masters level teacher preparation program. The methods course was specifically structured to help PTs learn to teach in a constructivist or reformed way by engaging in mathematical problem solving. One participant's experiences did not change her traditional view of mathematics; instead, her negative self perception as a mathematics learner was strengthened. Conversely, the other two participants' experiences showed that PTs were able to develop new perceptions about themselves and pupils as learners of mathematics. Both adopted a teaching role that focused on gaining mathematical understanding through a process of inquiry. The findings suggested that methods courses should shift from mastering practical skills to developing "habits of mind" such as "making sense of children's understanding and learning to take a reflective stance towards one's own teaching" (p. 93). This study highlighted the need for teacher education to expand beyond the preservice years to further develop these habits over time and help teachers adopt reformed teaching beliefs and practices.

Hart (2001) examined first-year teachers' levels of reformed teaching practice by conducting a two-year study that followed eight preservice teachers from their year-long teacher certification program and into their first year of teaching at urban schools. Through pre- and post-surveys, she collected data that examined mathematics beliefs, teacher reflection logs, and classroom observations. Hart found that although the beginning teachers struggled to maintain their reformed practices, they still tried to implement strategies they learned as preservice teachers. However, it was difficult to do so with contextual constraints such as traditional curricula that did not match their pedagogical philosophy. Implications for further research suggest that school context be considered in future studies of reformed teaching practices among beginning teachers.

The literature connecting reformed practices to pupil learning has ranged from smaller studies comparing two classrooms with researcher-constructed exams to large-scale studies that include surveys, interviews, limited observations, and standardized test scores. In their review of elementary mathematics curriculum reform, for example, Senk and Thompson (2003) discuss the research related to invented algorithms. They noted that children who invent algorithms have better mental computational skills, understand place value concepts, develop higher-order thinking, and have better problem-solving skills than students who are solely taught the traditional algorithms. Mokros (2003) conducted a small-scale study comparing two classrooms that used the *Investigations* curriculum, a reformed curriculum, with two classrooms that used a more traditional curriculum. She found that as pupils continued to solve more problems and articulate their strategies, they became more efficient and developed greater fluency with the method that made the most sense to them. Although

no differences were found in the two groups' computational fluency skills, those who used a reformed curriculum were able to solve more challenging word problems than those who used the traditional texts.

In 2000, the *ARC Center Tri-State Student Achievement Study* (ARC Center, 2003) compared the mathematics achievement of elementary school pupils in schools using reformed curricula with those using non-reformed curricula. A comparative design matching schools on SES, reading levels, ethnic composition, and level of English proficiency was implemented in Massachusetts, Illinois, and Washington. The study included over 100,000 pupils, split roughly equally between schools using reformed curricula and non-reformed curricula. Results showed that average mathematics scores on standardized state exams of pupils in reformed curricula schools were significantly higher than the scores of pupils in non-reformed curricula schools on every measure examined.

Another large-scale study, the *Mosaic I Study*, was conducted by the RAND Corporation to examine the relationship between reformed teaching practices and student achievement. Data collection and analyses for the first year were based on teacher questionnaires and pupil assessments using both multiple-choice and open-response items in two states that included four urban districts, 97 schools, and 324 mathematics teachers at both the elementary and middle school level (Klein et al., 2000). Reports of the first-year results, *Mosaic I*, found that achievement had a positive relationship with reformed teaching practice. Although this relationship was relatively weak, the positive trend was consistent across all sites. Results also indicated that pupils who received reformed teaching performed better on open-response items; however there were no significant differences in their performance on multiple-choice items in comparison to students who did not have reformed teaching. Their exposure to more context-based problem solving situations better prepared them for open-ended responses. Years later, RAND extended this study with *Mosaic II* to include teaching observations and student learning measures over time (Le et al., 2006). Similar to first-year findings, *Mosaic II* showed a consistently positive but weak relationship between reformed teaching practices and student achievement. Some results indicated that this relationship was greater with longer exposure to sustained reformed practices.

The aforementioned studies examined reformed teaching practices and its influence on pupil learning in mathematics. The first few studies focused on the role of teacher education in preparing teachers to adopt reformed teaching practices. It was evident that teacher education programs influenced teachers' beliefs, making them more aligned with reformed views of mathematics; however, it was challenging for beginning teachers to enact such beliefs in their classroom practices (Ebby, 2000; Hart, 2001). Thus, the study presented in this paper focused on beginning teachers; we acknowledge that the first few years of teaching are critical to shaping teaching practices, as beginning teachers are typically socialized into the culture of the school (Goos, 2005; Skott, 2001; Wideen et al., 1998). In addition, studies that examined the links among teacher education, teaching practices, and pupil learning in mathematics did not exist. The second set of studies examined the impact that reformed teaching had on pupil mathematics achievement (ARC Center, 2003; Klein et al., 2000; Le et al., 2006; Senk & Thompson, 2003). The findings generally showed a positive relationship between reformed teaching and pupil learning. One limitation with the large-scale comparison studies is that teachers' practices were not typically examined by direct observation. It is assumed that they are indeed teaching in a reformed manner because they are using a mandated reformed curriculum. However, studies on enacted curricula have shown that the same curriculum can look completely different when implemented in various classrooms (Collopy, 2003; Remillard & Bryans, 2004). Teaching is a complex intellectual activity that extends beyond curriculum implementation (e.g. Cochran-Smith & Lytle, 1999). It involves a high-level thinking process where teachers are constantly making decisions about their instruction, assessment, and how it best meets the needs of their pupils. This process is also couched in a larger political social context. Therefore, it is essential that studies examine the school contexts and observe classrooms to characterize teaching practices and learning opportunities accurately when making claims about pupil learning, rather than relying on what is assumed to be going on in the classroom as defined by a mandated curriculum. Consistent with NMP (2008) recommendations, it is especially important for empirical research to measure teaching practices beyond reformed teaching by including the learning experiences and perspectives of pupils.

Sawada et al. (2002) have made great efforts to define and measure reformed teaching practices operationally. They developed the RTOP, a highly reliable instrument, which has been shown to correlate with pupil achievement scores. Although the instrument was designed to measure reformed teaching practices in grades K-20, it has been primarily used in secondary schools and institutions of higher education. In contrast, this study uses the RTOP to examine the teaching practices of beginning elementary school teachers and the relationship of those practices to pupil learning. In the next section, we describe the research design, including contextual information and instrumentation.

Methods

This study is one piece in a portfolio of studies conducted by the Boston College Teachers for a New Era Evidence Team designed to examine and improve teacher education. TNE is an initiative funded by the Carnegie Corporation of New York and other funders intended to influence how eleven institutions across the nation deliver teacher education. Charged with examining the impact of teacher education and the process of learning to teach, Boston College's multi-disciplinary Evidence Team concluded that no single study or research design could begin to capture the impact of teacher education. Instead the team developed an evidence portfolio with quantitative, qualitative, and mixed-methods studies designed to examine impacts and relationships among teaching, learning, learning to teach, and social justice.

Initially, the current study was designed as a quasi-experiment comparing teachers from two pathways into teaching and their subsequent impact on pupil learning. Upon closer investigation of the two pathways, however, we determined that the two were much more similar than they were different. They were both highly selective in terms of preservice teachers who were admitted, they offered similar courses, placed an emphasis on teaching for social justice, and required comparable field placement experiences. It was no surprise, therefore, that there were no significant differences between them in graduates' teaching practices or pupils' learning outcomes (see Pedulla, Mitescu, Jong, Cannady, & Cochran-Smith, 2008). Therefore, the analysis described in this paper combined all of the teachers from these two pathways into one group in order to examine the relationship between their aggregated classroom practices and pupils' learning of mathematics content.

Research Design

Participants consisted of 22 beginning teachers in one large urban school district. The teachers were recent graduates of teacher preparation programs in either their first or second year of full-time teaching (see Table 1 for numbers of teachers by grade level and years of teaching). They were prepared by one of two teacher education programs, a university-based program or a residency-based program, both of which emphasized reformed teaching practice in their mathematics methods courses, as explained further in this section.

The beginning teachers in this study were observed twice during the teaching of one mathematics unit that took place during a 4–6-week time period in the spring of 2007. Elementary grade levels ranged from 1–6. Trained observers used the RTOP to rate participants' level of reformed teaching practices. District-developed tests for the mathematics unit of study were administered to pupils in the classroom. The following section provides a more detailed description of the school district, mathematics methods courses, learning outcome measures, and the RTOP utilized in this study.

Urban School District Context

Boyd et al. (2006) discuss the benefits of comparing various teacher education programs within a single labor market, specifically in the same school district. In this study, all of the teachers were located in the same urban school district, which was selected for several reasons. First and most importantly, a

Table 1
Number of Teachers by Grade Level

Grade level	First-year teachers	Second-year teachers	Total
1	4	2	6
2	4	0	4
3	3	4	7
4	0	2	2
5	1	1	2
6	0	1	1
Totals	12	10	22

significant percentage of the graduates of the university-based teacher education program find initial teaching placements in this urban district and all of the graduates of the residency-based training program are placed in this urban school district. Second, all schools in the urban school district use the same reformed mathematics curriculum for grades K to 6, which made this a propitious setting for the relationships we were interested in examining. Lastly, all teachers in the urban school district are required to administer district-developed tests at the end of each mathematics unit to measure pupil mastery of that particular mathematics content. Teachers at the same grade level administer these tests within the same week at all schools; moreover, the pace at which teachers cover the material in the unit is intended to be uniform across all schools and classrooms in the district, as articulated by a district-developed scope and sequence. This uniformity of instructional content and pacing helped provide a level of consistency with the content being taught among the same grade level classrooms in this study.

Mathematics Methods Courses

To determine whether the teacher participants in this study were prepared to teach with a focus on "reformed teaching practices," we examined the elementary school mathematics methods course syllabi for the two teacher education programs. A content comparison of the syllabi indicated that course goals and objectives were aligned with the NCTM mission. The two programs also used similar textbooks and assignments. The main difference between the courses was that the university-based course integrated an extensive amount of technology as a focus, and the residency-based course focused on preparing teachers to work in the urban district and by default, to use *Investigations*, rather than a variety of curricula. Hence, teachers in the university-based course were prepared to teach in a variety of school settings rather than the specific urban school district. These differences aside, it was clear that both methods courses supported a reformed teaching practice as evidenced by the readings, lesson requirements, and the questions addressed in reflective writing assignments. The goals of both courses centered on student mathematical understanding beyond procedures.

Learning Outcome Measures

In this study, all the teachers taught in the same urban school district and taught in grades 1–6. All classrooms in grades 1–5 in the urban school district used the same curriculum, *Investigations*, designed as a mathematics curriculum that aligned with NCTM standards and emphasized reformed teaching practice. In grade 6, teachers used the *Connected Mathematics Project* (CMP) curriculum. The urban school district required all elementary and middle school mathematics teachers to follow a scope and sequence for the curriculum. The pace at which teachers at each grade level covered the material in the unit was intended to be uniform across all schools and classrooms in the district; however, this was not necessarily the case due to selected schools piloting the revised edition of *Investigations*.

As part of the district curriculum, all mathematics teachers in the district also administered district-developed tests at the end of each unit to measure pupil mastery of that unit's mathematics content. These tests generally consisted of seven multiple-choice and three constructed response items. The tests were administered and scored by the classroom teachers who reported the number of items (or percent) correct to the school and district.

All the classroom teacher participants of this study administered and scored their pupils' mathematics post-tests after completing the unit of study that was observed by the raters. These tests measured the specific content of the unit just taught and thus, they were intended to be sensitive measures of the content and instruction in that unit. The district tests were used as a measure of student outcomes and provided a specific measure that could be linked to observed teaching practices. Specifically, in this study the student assessments were used to connect practices associated with reformed teaching practices to student learning, as measured by the district-mandated unit post-tests, to address this gap in the literature (Lubienski, 2005; Wilson, Floden, & Ferrini-Mundy, 2001).

Reformed Teaching Observation Protocol

Trained observers rated teachers by using the RTOP, an instrument designed by the Evaluation Facilitation Group of the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) in 1999. We chose an established, existing instrument in part to be responsive to the criticism that in previous research, the instrumentation used was often ad hoc with little evidence to support its use. The RTOP measures "reformed" teaching practices—that is active-learning, inquiry-based and problem-solving strategies,[1] in K-20 science, technology, engineering, and mathematics courses. We specifically chose this

instrument for the study reported in this paper, because it was consistent with the goals of the *Investigations* and *CMP* curricula used in the urban school district. It was also was aligned with the objectives of both teacher education programs' mathematics methods courses.

The RTOP instrument consists of 25 items that fall into three broad categories: (1) lesson design and implementation; (2) content (propositional and procedural knowledge); and (3) classroom culture (communicative interactions and student/teacher relationship) (see Appendix). The RTOP items clearly reflect a reformed practice with characteristics that are hallmarks of reformed teaching practices in STEM classrooms. As examples of this, item 11 states: "Students and teacher used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena," while item 22 states: "Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence." Each of the 25 items are rated on a five-point Likert scale ranging from 0 to 4 with "0" indicating no evidence of the reformed teaching characteristic and "4" representing clear evidence that an attribute is present and integrated throughout the lesson. A total score of 50 or above (the maximum score is 100) on the RTOP is indicative of reformed teaching (MacIsaac & Falconer, 2002). The reformed teaching score of 50 is equivalent to an average rating of 2 on each item. Here we report scale scores as the mean of the items rather than the total score across items. Therefore, a 2 or higher is indicative of reformed teaching practice.

The researchers who developed the RTOP instrument report inter-rater reliability of .95, indicating a very high level of consistency of ratings across raters (Sawada et al., 2002). After a full day of training, the inter-rater reliability for the observers for this study yielded a similarly high inter-rater reliability of .94 for the RTOP. This reliability was consistent with previous studies using the RTOP and was clearly acceptable. We concluded that our raters were consistent enough to observe teachers.

Results

In the following section, we show the results of the RTOP scores as well as pupil learning outcomes. We also examine the relationship between the two measures to directly examine the connection between reformed teaching practices and pupil learning.

The RTOP Scores

The average RTOP score for the 22 participants in this study was 2.18, indicating that teachers across both teacher education programs taught with a reformed teaching practice. As noted earlier, an item mean score of 2 (out of 4) was equivalent to an RTOP total score of 50 out of 100, which indicated that teaching practices reflected a moderate degree of reformed teaching. For example, a score of 50 would indicate that a teacher received an approximate raw score of "2" in each of 25 items. In order to score a "2" within the 0–4 point scale, a characteristic needs to be observed more than one time (i.e., students were reflective about their learning), and it can be challenging to observe various characteristics within a 50-minute lesson. In addition, it is difficult to determine whether this score can be attributed to what these beginning teachers learned in their mathematics methods courses, the role that their school sites played, and/or the influence of the reformed curriculum. That is to say, we acknowledge that learning to teach is a multi-leveled process that takes place within many contexts. Table 2 shows a breakdown of the mean scores and standard deviations of the five scales within the RTOP. The highest mean was 2.42 for Classroom Culture–Student/Teacher Relationship, followed by a 2.31 for Lesson Design and Implementation. Content–Propositional Knowledge was next with a 2.20. Classroom Culture–Communicative Interactions had a lower mean of 2.03. Finally, Content–Procedural Knowledge had the lowest mean score of 1.94, indicating that, on average teachers just missed meeting the threshold of a reformed teaching practice (2.0) in this category.

It was unclear why teachers scored lower on the Content–Procedural Knowledge scale. This scale placed a greater emphasis on pupils' actions in

Table 2
RTOP Sub-Scale Scores

Scale	Mean	SD
Lesson design and implementation	2.31	.67
Content propositional knowledge	2.20	.69
Content procedural knowledge	1.94	.75
Classroom culture communicative interactions	2.03	.65
Classroom culture student-teacher relationships	2.42	.78

comparison to the other four scales; the characteristics may have been difficult to observe by one person, if pupils worked in small groups.

Overall, we could clearly state that as a collective group, the beginning teachers in this study displayed many of the classroom characteristics that have been associated with reformed teaching practice in mathematics. Given that some studies have found that beginning teachers struggle with reformed teaching practices (Ebby, 2000; Hart, 2001; Lubienski, 2000), it is promising that these beginning teachers' classroom practices seem to reflect more reformed teaching practices. We cannot pinpoint any specific factors within the teacher education programs that fostered a reformed practice beyond what is represented on the respective syllabi, the assignments, and fieldwork requirements of the two programs. However, we can say with confidence that the teachers in this study were exposed to reformed practices in their mathematics methods course and that both programs offered induction and mentoring programs up to 3 years post-graduation. Friedrichsen, Chval, and Teuscher (2007) found that it was helpful for beginning teachers of science and mathematics to have multiple support structures and mentors to succeed during the challenging first 3 years of teaching. Though several types of support were offered to our participants through the urban school district and both teacher education programs, we did not examine their effectiveness on teachers' practices. Next, we will present the pupils' mathematics learning outcomes.

Learning Outcomes

To obtain a measure of pupil's content learning for each teacher, we calculated the classroom mean of the proportion of items answered correctly by each student in that class. We recognize that there were weaknesses with this measure (i.e., the implicit assumption of equivalence of scores at different grade levels), but this was the only measure of pupil achievement available for all pupils. Additionally, we wanted learning outcomes to reflect the teaching observed during the study. Pre-tests for nine classrooms had a mean mathematics score of .41 for the particular unit of instruction. Post-tests for all 22 classrooms had a mean score of .73. Due to the small sample of pre-tests administered, we did not have sufficient power to examine whether statistically significant pre-post gains occurred. However, scores for the pre-test were similar among classes, which indicated that no major initial differences existed among those classrooms. The mathematics post-test scores were used to examine the relationship between pupils' learning in mathematics and teachers' scores on the RTOP. These results are presented in the next section.

Relationship between Measures

The correlation between the teachers' RTOP scores and their pupils' post-test mean mathematics content scores was .56 ($p < .05$) (see Figure 1), which suggests that reformed teaching is positively and significantly related to pupils' mathematics learning. The two measures have 32% of their variance in common. Teachers who implemented reformed teaching practices to a higher degree tended to have pupils who scored higher on the district mathematics test. Our study does not attempt to claim causality, but rather focuses on the correlational relationship. The non-experimental nature of the design precludes causal statements.

This finding is consistent with the literature discussed earlier where positive learning outcomes were connected to reformed teaching practices in mathematics and the use of reformed teaching practices (ARC Center, 2003; Klein et al., 2000; Senk & Thompson, 2003). Furthermore, this study connects classroom teaching practices to pupil learning through direct observation of teaching instead of through teachers' self-reported practices. This is an important difference, since observation provides a more direct measure of reformed teaching. We highlight that participants in this study were beginning teachers and argue that they can have a positive influence on pupil learning, which is contrary to work claiming that beginning teachers spend most of their efforts thinking about their practices rather than focusing on pupil learning (Hammerness et al., 2005).

To further investigate the relationship between reformed teaching practices and pupil learning, we examined the correlations between the RTOP sub-scales and class mean post-test scores (see Table 3). Results indicate that Content–Propositional Knowledge ($r = 0.58$), Classroom Culture–Student-Teacher Relationships ($r = 0.54$), and Content–Procedural Knowledge ($r = 0.51$) sub-scales were statistically significantly related to pupil learning outcomes ($\alpha = .05$). The Lesson design and Implementation ($r = 0.36$) and Classroom Culture–Communicative Interactions ($r = 0.32$) sub-scales were not statistically significantly correlated with the pupil learning outcomes. It is not clear why certain scales correlated more highly with pupil assessment scores, but we indicate some possible reasons.

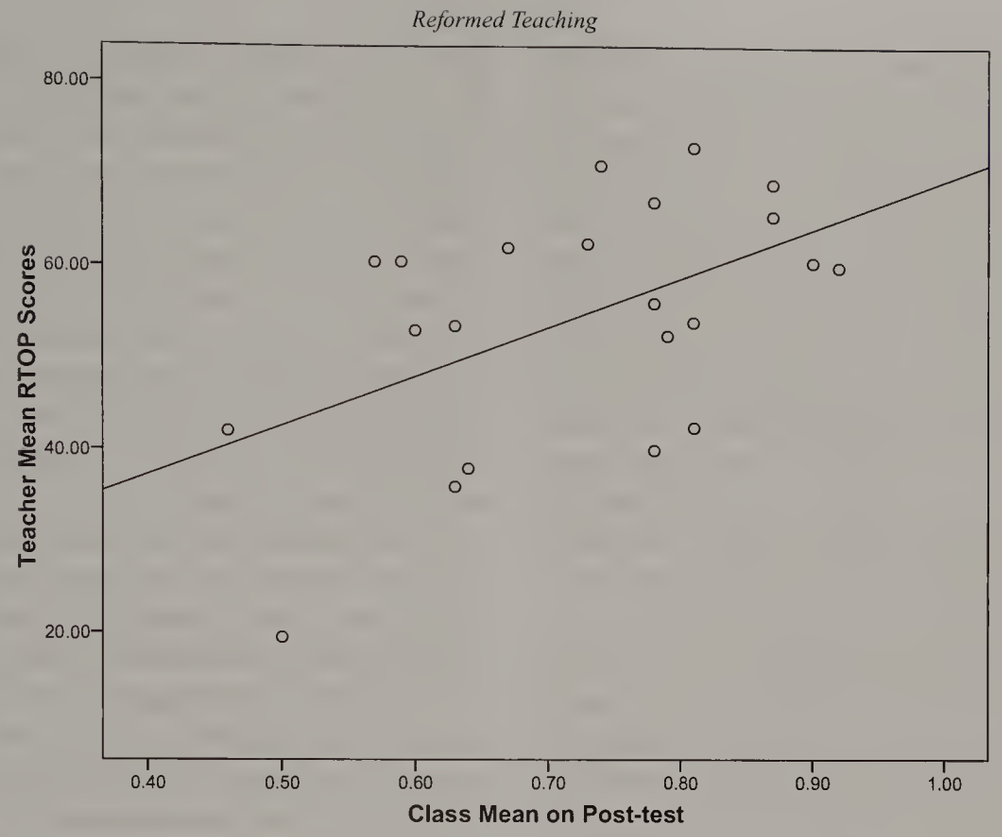

Figure 1. Scatter plot of reformed teaching and pupil learning relationship.

Table 3
Correlations of RTOP Sub-Scale Scores and Class Mean Post-Test Scores

Scale	*r*
Lesson design and implementation	.36
Content Propositional Knowledge	.58**
Content Procedural Knowledge	.51*
Classroom Culture Communicative Interactions	.32
Classroom Culture Student-Teacher Relationships	.54**

*Correlation is significant at the .05 level (2-tailed).
**Correlation is significant at the .01 level (2-tailed).

The two sub-scales with the highest correlations focused on the role of the teacher more so than the other three scales. An important aspect of the Content–Propositional Knowledge scale was its emphasis on the teachers' knowledge of the subject. This finding is consistent with that of Hill, Rowan, and Ball (2005), who found that teachers' mathematical knowledge is highly related to pupil learning. The Classroom Culture–Student-Teacher Relationship scale directly examined whether a teacher acted as a facilitator and provided support for pupils in their learning. The NCTM Teaching Principle acknowledges the multiple roles of teachers and the importance of knowing their students, which was a key factor in this scale. Teaching in itself is multilayered (Cochran-Smith & Zeichner, 2005), and the differences found among the RTOP sub-scales in relation to pupil learning highlight the complexities involved in reformed teaching, which should be further investigated.

In addition, it is important to note that all teachers taught in a large urban school district, where most participating schools had a high percentage of students on free/reduced lunch, students of color, and bilingual learners. Most schools were in the "Needs Improvement" category, not meeting NCLB AYP goals. The fact that our participants were in the same district and used the same curriculum provides some level of control for their beginning school contexts. It is encouraging to see that these beginning teachers were able to reflect reformed teaching practices and have a positive influence on their pupils' learning of mathematics.

Discussion and Implications

Research studies that directly examine the teaching practices of the graduates of teacher education

programs are rare, and perhaps more rare are studies that examine the links between the teaching practices of teacher preparation program graduates and the learning of their pupils (Lubienski, 2005; Wilson et al., 2001). In addition, according to the NMP (2008) report that we described at the beginning of this article, no high-quality research was found that favored either student-centered or teacher-directed instruction. However, the NMP report made no mention about the requirements used to determine what was considered "high-quality" research. In this era of increased accountability, several mathematics educators have noted that while NCLB has placed added pressure on teachers to improve pupil achievement (as evidenced by state-mandated tests), it has also hindered school-based research that examines teaching practices (Chval, Reys, Reys, Tarr, & Chávez, 2006). With the challenges of conducting research in schools, we were pleased to have been able to examine reformed teaching practices and find a positive link to pupil learning in elementary school mathematics. This study adds to the evidence that higher scores on the RTOP are related to higher scores in mathematics achievement (MacIsaac & Falconer, 2002; Sawada et al., 2002). Thus, higher levels of reformed teaching practices are connected to higher pupil learning scores in mathematics.

This study found not only that it was possible for teachers in their first 2 years of teaching to teach with a reformed pedagogy, but it also linked higher degrees of reformed teaching to higher pupil learning in mathematics ($r = .56$; $p < .05$). Given that some studies have found that beginning teachers struggle with reformed teaching practices (Ebby, 2000; Hart, 2001), it is promising that most of these beginning teachers' classroom practices reflected more reformed teaching practices. Findings from this study imply that it is possible for beginning teachers to both adopt a reformed teaching practice and those who do so to a greater degree have pupils with higher mathematics test scores. As preservice teachers, their mathematics methods course focused on reformed teaching practices that were reinforced by the school district's curriculum. It is unknown the extent to which these factors played a role in teachers' practices, but previous research suggests that reinforcing experiences have the potential to influence teachers' beliefs and practices (Clift & Brady, 2005; Ebby, 2000).

We fully recognize that there were limitations to this study and room for improvement in the research design. An initial comparison study was adapted here, by combining two groups of teachers, due to the shared characteristics and lack of measurable differences between the two pathways into teaching (Pedulla et al., 2008). The combined group of teachers who participated in this study allowed us to examine teaching practices and the level of reformed pedagogy. In a future study, we would recommend that participants complete a survey about their beliefs and experiences in both teacher education and induction programs. Interviews would also help capture teachers' perspectives.

We recommend the use of the RTOP as an established instrument that measures reformed teaching practices in science, mathematics, and engineering for future studies (Sawada et al., 2002). The RTOP has primarily been used to improve teaching in mathematics and science departments at secondary schools and institutes of higher education rather, but rarely in schools of education (Judson & Lawson, 2007; MacIsaac, Sawada, & Falconer, 2001). We suggest the RTOP be used as a way of discussing and defining reformed teaching in university mathematics methods courses in schools of education and/or professional development courses, which have not been studied. For the past decade, we have begun to learn about the type of specialized knowledge elementary school teachers need to teach mathematics effectively (Hill et al., 2005), which require an in-depth knowledge of the content, teaching, and pupils. While the research on teacher knowledge has made great contribution to the field of mathematics education, more research is needed to examine classroom practices and how to improve pupil learning and understanding of mathematics content beyond what is measured by state-mandated standardized tests. Findings from this study support previous research suggesting that reformed teaching practices offer promising possibilities (Senk & Thompson, 2003).

To prepare beginning teachers to enact a reformed pedagogy advocated by NCTM and NSF, teacher education and mentoring/induction programs must support preservice and beginning teachers' learning of this practice. The RTOP is one way of providing clear strategies that teachers can integrate into their classrooms, and examining the development of reformed practice over time. The school culture plays an important role in beginning teachers' practices; thus, orienting beginning teachers to effectively implement and modify reformed curricula to meet the needs of their

pupils is necessary. We know that requiring the use of reformed curricula does not mean that teachers will necessarily teach with a reformed practice (Collopy, 2003; Remillard & Bryans, 2004). Thus, we suggest that beginning teachers are engaged in school cultures where they are reflecting upon their practices, examining pupil work, and collaborating with others to improve their teaching. In terms of further research, we recommend a thorough examination of the school and classroom context and the relationship of reformed teaching practices to other pupil learning outcome measures and work samples, possibly in other grades and content areas (e.g., science). It is important for beginning teachers to have support in their school contexts. Thus, a future study could further examine school cultures and the influence that mentors, colleagues, and administrators have on beginning teachers' practices. Observing more experienced teachers would also be important so that we may understand the similarities and differences between them and beginning teachers in terms of the relationship between reformed teaching practices and pupil learning.

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Authors' Notes

TNE is an initiative funded by the Carnegie Corporation of New York and other funders to change how teacher education is understood and enacted at eleven selected institutions across the nation. During the period when the work described in this paper was completed, the Evidence Team included Boston College faculty members and administrators, Marilyn Cochran-Smith (Chair), Alan Kafka, Fran Loftus, Larry Ludlow, Patrick McQuillan, Joseph Pedulla, and Gerald Pine; TNE Administrators, Jane Carter and Jeff Gilligan; and doctoral students in either Curriculum and Instruction or Educational Research, Measurement and Evaluation, Joan Barnatt, Robert Baroz, Lisa D'Souza, Sarah Enterline, Ann Marie Gleeson, Cindy Jong, Kara Mitchell, Emilie Mitescu, Aubrey Scheopner, Karen Shakman, Yves Fernandez Solomon, and Diana Terrell.

[1] Gross, N.A. and Hickman, P. An Evaluation Protocol for 21st Century Instructors, p. 1.

Appendix

Reformed Teaching Observation Protocol (RTOP)

BACKGROUND INFORMATION

Name of school: _____

Name of district: _____

Name of teacher: _____

Grade level(s): _____

Date of observation: _____

Name of observer: _____

Start time: _____

End time: _____

CONTEXTUAL BACKGROUND ACTIVITY

PART A: THE CLASSROOM SETTING

TOTAL number of students: _____

Number of male students: _____

Number of female students: _____

Number of (visible) minority students: _____

Number of (visible) majority students: _____

Number of students with disabilities*: _____

Number of ELL students*: _____

Teacher's aide or other adults: _____

* Most likely answered by the teacher after the lesson

WRITTEN DESCRIPTION

Physical Description:

- *Please describe the physical classroom environment, noting the arrangement of desks or tables (e.g., clusters, rows), the math-related materials posted on the walls, the math-related materials visible in the room (e.g., bins of geo-boards, calculators, tiles, unifix cubes, etc.), and math-related information written on the blackboard.*

- *Please describe the math-related curriculum materials visible in the room as well as the curriculum materials used during the observed lesson. Please note the curriculum's title, publisher, and page number. If possible, please try to obtain copies of curriculum materials distributed to students (e.g., worksheets, assessments).*

- *Please describe any technology visible in the room (e.g., overhead projector, TV/VCR, computers). Please describe the type and number of computers.*

Lesson Description

- *Please describe the content of the lesson and how it was presented to the class (e.g., Mr. L. taught a lesson on surface area and volume which included . . .)*

- *Please present a bulleted chronology of the lesson (e.g., 5 minutes small group work, 10 minutes whole class discussion)*

PART B: ***In the space below please provide notes of the lesson observed. In the left-hand column, track the time at 5–10 minute intervals.***

Time	Description of events (teacher's and students' activities)

PART B: Continued

Time	Description of events (teacher's and students' activities)

III. LESSON DESIGN AND IMPLEMENTATION

	Never Occurred				Very Descriptive
1. The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.	0	1	2	3	4
2. The lesson was designed to engage students as members of a learning community.	0	1	2	3	4
3. In this lesson, student exploration preceded formal presentation.	0	1	2	3	4
4. This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.	0	1	2	3	4
5. The focus and direction of the lesson was often determined by ideas originating with the students.	0	1	2	3	4

IV. CONTENT

Propositional knowledge

6. The lesson involved fundamental concepts of the subject.	0	1	2	3	4
7. The lesson promoted coherent conceptual understanding.	0	1	2	3	4
8. The teacher had a solid grasp of the subject matter content inherent in the lesson.	0	1	2	3	4

9. Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so. 0 1 2 3 4

10. Connections with other content disciplines and/or real-world phenomena were explored and valued. 0 1 2 3 4

Procedural knowledge

11. Students and teacher used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena. 0 1 2 3 4

12. Students made predictions, estimations, and/or hypotheses and devised means for testing them. 0 1 2 3 4

13. Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures. 0 1 2 3 4

14. Students were reflective about their learning. 0 1 2 3 4

15. Intellectual rigor, constructive criticism, and/or the challenging of ideas were valued. 0 1 2 3 4

V. CLASSROOM CULTURE

Communicative Interactions

	Never Occurred				Very Descriptive
16. Students were involved in the communication of their ideas to others using a variety of means and media.	0	1	2	3	4
17. The teacher's questions triggered divergent modes of thinking.	0	1	2	3	4
18. There was a high proportion of student talk and a significant amount of it occurred among students.	0	1	2	3	4
19. Student questions and comments often determined the focus and direction of the classroom discourse.	0	1	2	3	4
20. There was a climate of respect for what others had to say.	0	1	2	3	4

Student/Teacher Relationship

21. Active participation of students was encouraged and valued. 0 1 2 3 4

22. Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence. 0 1 2 3 4

23. In general the teacher was patient with students. 0 1 2 3 4

24. The teacher acted as a resource person working to support and enhance student investigations. 0 1 2 3 4

25. The metaphor "teacher as listener" was characteristic of this classroom. 0 1 2 3 4

Additional comments you may wish to make about this lesson.

Clarifying questions to ask the teacher after the observation:

- Was today a typical day in your classroom? Why or why not?

- Did today's lesson turn out as you planned? In what ways?

- Do you sometimes make changes to the curriculum? Can you describe those?

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972-86-477-648. Questions concerning proposals and/or solutions can be sent via e-mail to <eisenbt@013.net>. Solutions to previously stated problems can be seen at http://ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before December 15, 2010.

• 5122: *Proposed by Kenneth Korbin, New York, NY*

Partition the first 32 non-negative integers from 0 to 31 into two sets A and B so that the sum of any two distinct integers from set A is equal to the sum of two distinct integers from set B and vice versa.

• 5123: *Proposed by Kenneth Korbin, New York, NY*

Given isosceles triangle ABC with $\overline{AB} = \overline{BC} = 2011$ and with cevian $\overline{BD}$. Each of the line segments $\overline{AB}$, $\overline{BD}$, and $\overline{CD}$ have a positive integer length with $\overline{AD} < \overline{CD}$. Find the lengths of those three segments when the area of the triangle is at its minimum.

• 5124: *Proposed by Michael Brozinsky, Central Islip, NY*

If $n > 2$ show that $\sum_{i=1}^{n} \sin^2\left(\frac{2\pi i}{n}\right) = \frac{n}{2}$.

• 5125: *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

Let a, b, c be positive real numbers such that $a^2 + b^2 + c^2 = 3$. Prove that

$$\frac{ab}{2(c+a)+5b} + \frac{bc}{2(a+b)+5c} + \frac{ca}{2(b+c)+5a} < \frac{11}{32}.$$

• 5126: *Proposed by Pantelimon George Popescu, Bucharest, Romania, and José Luis Díaz-Barrero, Barcelona, Spain*

Let a, b, c, d be positive real numbers and $f : [a, b] \to [c, d]$ be a function such that $|f(x) - f(y)| \geq |g(x) - g(y)|$, for all $x, y \in [a, b]$, where $g : R \to R$ is a given injective function, with $g(a), g(b) \in \{c, d\}$.

Prove

(i) $f(a) = c$ and $f(b) = d$, or $f(a) = d$ and $f(b) = c$.

(ii) If $f(a) = g(a)$ and $f(b) = g(b)$, then $f(x) = g(x)$ for $a \leq x \leq b$.

• 5127: *Proposed by Ovidiu Furdui, Cluj, Romania*

Let $n \geq 1$ be an integer and let $T_n(x) = \sum_{k=1}^{n} (-1)^{k-1} \frac{x^{2k-1}}{(2k-1)!}$, denote the $(2n-1)$th Taylor polynomial of the sine function at 0. Calculate

$$\int_0^{\infty} \frac{T_n(x) - \sin x}{x^{2n+1}}\, dx.$$

CALL FOR proposals

School Science and Mathematics Special Issue on STEM Education

The *School Science and Mathematics* editorial staff requests the submission of manuscripts for an upcoming special issue on Science, Technology, Engineering, and Mathematics (STEM) education. In a growing era of STEM related policy, research, and practice, there is an emerging need to disseminate cutting edge educational research focused on STEM in PreK-20. In particular, we are seeking manuscripts on integrated STEM in the following areas:

- Implications of STEM related policy at the federal, state, or local levels
- Studies of PreK-12 teachers and or schools/districts implementing STEM programs and/or themed schools
- Post-secondary STEM discipline student recruitment programs—growing of the pipeline
- Integration of STEM careers into K-12 curriculum
- Partnerships between private and public organizations, higher education, and PreK-12 schools to address regional, state, or national STEM talent shortages
- Studies of the impact of integrated STEM instruction on student achievement in science and/or mathematics

All manuscripts must meet the length and format guidelines for the journal (see the information at http://www.ssmj.tamu.edu). A group of Reviewers and Associate Editors will be identified to review the manuscripts. A total of five manuscripts will be selected for publication in the STEM Special Issue to be published in January 2012.

Manuscripts need to be submitted by January 31, 2011 through the Scholar One website (http://mc.manuscriptcentral.com/ssm). Please indicate in your cover letter that your manuscript is to be considered for the STEM special issue.

Dr. Carla C. Johnson, Associate Professor of Science Education, University of Cincinnati, will serve as the Guest Editor for this special issue. If you have questions regarding the appropriateness of a topic/manuscript for this special issue, please contact Dr. Johnson at Carla.johnson@uc.edu.

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Journal Office:

Heather R. Rodriguez, Managing Editor
School Science and Mathematics Journal
Texas A&M University
4232 TAMU Harrington
College Station, TX 77843-4232

Circulation Data:

Reader: K-graduate leaders and teacher educators
Frequency of issue: 8 times per year
Copies per issue: 3001-4000
Sponsorship: Professional organization

Publication Guidelines:

Manuscript length, 6-25 pages, including references

Review Information:

Type of review: Blind review
No. of external reviewers: Three
No. of in-house reviewers: Up to three
Fees charged to review: None
Editor considers recommendations of reviewer: Yes
Time to review: 6-7 months
Reviewers' comments: Yes
Invited articles: 5% or less

Manuscript topics:

Science, mathematics, and connections between science and mathematics for grades K-graduate and teacher education, especially science and mathematics articles that deal with assessment, attitudes, beliefs, curriculum, equity, research, translating research into practice, learning theory, alterative conceptions, philosophy and history of science, sociocultural issues, special populations, technology, nontraditional forms of instruction, and science/technology/society.

Manuscript guidelines/comments:

Submission: All manuscripts are subject to the review process. Manuscripts should not have been previously published nor be under consideration for publication in any other journal.

Source of publication guidelines: Publication Manual of the American Psychological Association, 5th Edition.

Membership: At least one author of any feature article must be a member of the School Science and Mathematics Association at the time of acceptance of the article. The membership provides a one-year subscription to the journal.

Manuscript preparation:

All manuscripts must be prepared according to the 5th Edition of the Publication Manual of the American Psychological Association, typed double-spaced using a 12-point or larger font, and printed on 8 1/2- by 11-inch paper. Manuscripts should be limited to 25 pages, excluding figures, tables, and appendices. **Submissions that are not APA style or exceed the length limitation will be returned.**

Manuscript Submission: All manuscripts must be submitted electronically at the web site http://mc.manuscriptcentral.com/ssm. The following components are required:

1. An abstract not to exceed 200 words on a separate page
2. To maintain anonymity of the author(s), author(s) citing their own work should cite as follows:
   In text: Author (1999) found...
   On reference list: Author (2005). Journal Title. (Do not include title of article or volume and page #)
3. Graphics submitted as publication-ready copy on white background with black type. Each table or figure should be on a separate page at the end of the manuscript, with a note within the ms where the graphic should be placed. Use no smaller than 8-point font for text on figures; use no smaller than 11-point font for tables. Figures and tables should be no wider than 6.75 inches.

Manuscripts submitted for review will be evaluated on the following:

All manuscripts:

Relevence, timeliness, and significance
Addresses K through graduate classroom or teacher education issues
Explicitness, clarity, logicality, conciseness
Literature review
Theoretical/literature-based framework

Research manuscripts only:

Design and methodology
Analyses of data
Conclusions based on results
Results related to professional practice and literature
Enough information to enable replication (quantitative)

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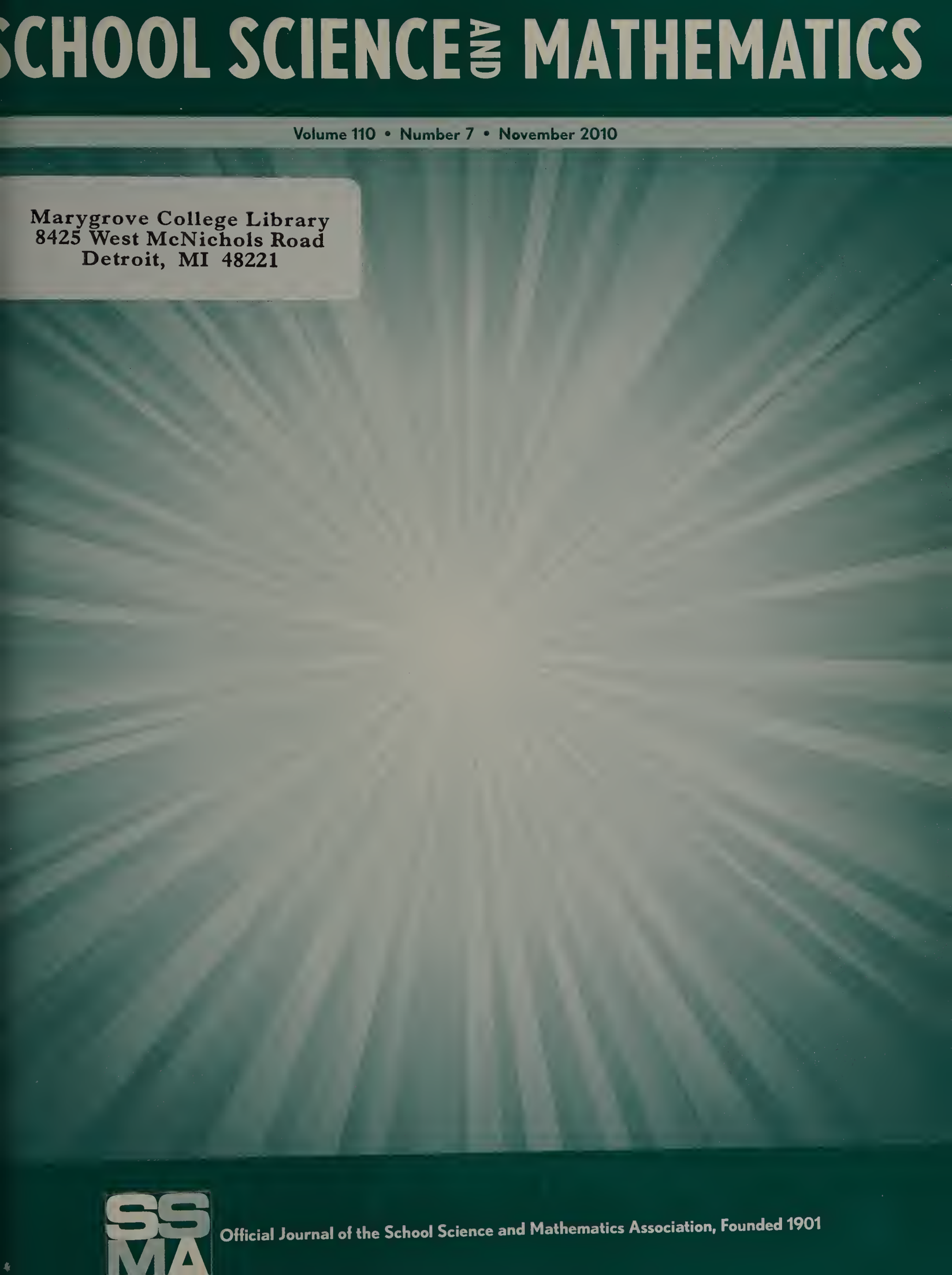

SSMA Official Journal of the School Science and Mathematics Association, Founded 1901

School Science and Mathematics

Journal Office

(All publication matters except advertising and reprints)

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School Science and Mathematics (Print ISSN: 0036-6803, Online ISSN: 1949-8594) is published in January, February, March, April, September, October, November and December on behalf of the School Science and Mathematics Association by Wiley Subscription Services, Inc., a Wiley Company, 111 River St., Hoboken, NJ, 07030-5774. Periodical postage paid at Hoboken, NJ and additional offices.

Postmaster: Send all address changes to *School Science and Mathematics*, Journal Customer Services, John Wiley & Sons, Inc., 350 Main St., Malden, MA 02148-5020.

Information for Subscribers: *School Science and Mathematics* is published in eight issues per year. Subscription prices for 2010 are: Institutional Print & Online rate: US$250 (the Americas), US$250 (Rest of World), €180 (Europe) £153 (UK). Prices are exclusive of tax. Asia-Pacific GST, Canadian GST and European VAT will be applied at the appropriate rates. For more information on current tax rates, please go to www.wileyonlinelibrary.com/tax-vat. The institutional price includes online access to the current and all online back files to January 1, 1997, where available. For other pricing options, including access information and terms and conditions, please visit www.wileyonlinelibrary.com/access.

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Production Editor: John Siever (ssm@wiley.com)

Electronic Access: This journal is available online at *Wiley Online Library*. Visit http://wileyonlinelibrary.com/ to search the articles and register for table of contents and email alerts.

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ISSN: 0036-6803 (Print)
ISSN: 1949-8594 (Online)
Printed in the US by The Sheridan Group.

IN THIS issue

Intentional Integration of Mathematics Content Instruction with Constructivist Pedagogy in Elementary Mathematics Education

Gerald R. Fast, Judith E. Hankes

The purpose of the research was to improve the effectiveness of instruction in constructivist pedagogy in a college elementary mathematics education course through intentional integration of instruction in mathematics content. Instructors of this course previously used examples involving mathematics content on an ad hoc basis in an attempt to illuminate desirable constructivist pedagogy but discovered that they were ineffective because students experienced difficulty with the mathematics content itself. An instrument was created to assess students' mathematics content knowledge required to understand these examples. Based on the outcome of the asscssment, intentional instruction of mathematics content using anchoring examples was integrated with pedagogical instruction. Results showed significant improvement in mathematics content knowledge and confidence in that knowledge with a better understanding of constructivist pedagogy.

A Teacher's Conception of Communication in Geometry Proofs

Mary K. Gfeller

Mathematical proof has many purposes, one of which is communication of the reasoning behind a mathematical insight. Research on teachers' views of the role that proof plays as mathematical communication has been limited. This study describes how one teacher conceptualized proof communication during two units on proof (coordinate geometry proofs and Euclidean proofs). Based on classroom observations, the teacher's conceptualization of communication in written proofs is recorded in four categories: audience, clarity, organization, and structure. The results indicate differences within all four categories in the way the idea of communication is discussed by the teacher. Implications for future studies include attention to teachers' beliefs about learning mathematics in the process of understanding teachers' conceptions of proof as a means of mathematical communication.

Re-creating a Recipe for Science Instructional Programs: Adding Learning Progressions, Scaffolding, and a Dash of Reading Variety

Scott W. Slough, William H. Rupley

The purpose of this article is to focus on the development and refinement of a science instructional design program arguing for the feasibility and usability of integrated reading and science instruction as implemented in third- and fourth-grade science classrooms to meet the learning needs of diverse learners. These instructional components are easily inserted into existing programs that build students' science background knowledge and abilities to apply learning through scaffolded activities focused on (1) providing structured opportunities for students to engage in hands-on activities; (2) increasing vocabulary knowledge and understanding of concept-laden terms; and (3) reading paired narrative and informational science texts. Extensive research shows that as students transition from third to fourth grade and beyond, they are often challenged in science by new vocabulary coupled with new concepts. Active ingredients of our reconceptualized science instructional design program are narrative informational texts, hands-on science activities, and science textbook(s).

Elementary School Teachers' Manipulative Use

Lida J. Uribe-Flórez, Jesse L. M. Wilkins

Using data from 503 in-service elementary teachers, this study investigated the relationship between teachers' background characteristics, teachers' beliefs about manipulatives, and the frequency with which teachers use manipulatives as part of their mathematics instruction. Findings from the study show that teachers' grade level and beliefs about manipulatives are important predictors of teachers' use of manipulatives in their mathematics instruction.

Intentional Integration of Mathematics Content Instruction with Constructivist Pedagogy in Elementary Mathematics Education

Gerald R. Fast
Judith E. Hankes
University of Wisconsin Oshkosh

The purpose of the research was to improve the effectiveness of instruction in constructivist pedagogy in a college elementary mathematics education course through intentional integration of instruction in mathematics content. Instructors of this course previously used examples involving mathematics content on an ad hoc basis in an attempt to illuminate desirable constructivist pedagogy but discovered that they were ineffective because students experienced difficulty with the mathematics content itself. An instrument was created to assess students' mathematics content knowledge required to understand these examples. Based on the outcome of the assessment, intentional instruction of mathematics content using anchoring examples was integrated with pedagogical instruction. Results showed significant improvement in mathematics content knowledge and confidence in that knowledge with a better understanding of constructivist pedagogy.

Elementary education (K-8) preservice teachers are generally required to take at least one course that focuses primarily on the pedagogy of mathematics at the K-8 level. The essence of such a course is generally not instruction in mathematics content (Grouws & Schultz, 1996), yet in the process of discussing effective methods and techniques for teaching mathematics, examples of such instruction must necessarily involve mathematics content. Instructors of mathematics methods courses might assume that the mathematics content utilized in these examples would be part of the prior knowledge of the students in their courses because the content would be that of the elementary mathematics curriculum. Also, the students would likely have studied mathematics much beyond that level, including in many cases, two or three additional mathematics courses at the college level.

There is considerable evidence that teachers' mathematics content knowledge contributes positively to effective mathematics instruction (Hill & Lubienski, 2007; Hill, Rowan, & Ball, 2005). Research, however, has also shown that the separation of content and pedagogy often creates a disconnect (Ball, 2000), resulting in teachers not understanding how to apply their mathematics content knowledge for the greatest effectiveness in teaching and student learning. Hill, Rowan, and Ball emphasize that teachers must have an understanding of the mathematical knowledge that is specific to teaching children. For example, in addition to knowing how to compute, a teacher might need to know how and why specific mathematics procedures work, how best to define a term for children at a particular grade level, or how to interpret, remediate, or prevent students' errors. Furthermore, students' errors may be indicative of misconceptions that the students have developed or are in the process of developing (Fast, 2007). Misconceptions are generally highly resistant to change once they have been fully developed (Smith, 1992), and it is thus desirable to prevent misconceptions or curtail their development at the earliest opportunity (Fast).

Fusaro (n.d.) states that Hill et al. (2005) found that teachers' deep and flexible understanding of math concepts helped them provide richer learning opportunities for students such as using better concrete models and more meaningful examples. For instance, in teaching the associative property for addition, a teacher might use the example:

$$387 + (950 + 5) = (387 + 950) + 5$$

Fusaro (n.d.) points out that although this example illustrates the associative property, the regrouping in the example does not really make the calculation any easier and thus does not do much to demonstrate the usefulness of the property. However, if the example were changed to:

$$(387 + 950) + 50 = 387 + (950 + 50)$$

then the calculation would become much easier because 387 + (950 + 50) now is readily seen to be 387 + 1,000 = 1,387.

From a mathematical perspective either example could be used to illustrate the associative property, but from a pedagogical perspective, the latter example not only illustrates the property but highlights its usefulness. Thus, in teaching, not just any example will do but teachers need to design examples carefully to illuminate key aspects of the mathematics concept including its usefulness and application (Fusaro, n.d.).

According to current research on teaching mathematics, a constructivist approach is key to building the deep mathematics understanding promoted by the National Council of Teachers of Mathematics (NCTM) Standards (Brooks & Brooks, 1999; Eisenhart et al., 1993; NCTM, 2000). Contrary to learning through direct instruction, constructivism typically involves hypotheses, explorations, observations, discoveries, reflections, and finally tentative conclusions about the nature of the concept under investigation (Brooks & Brooks). The students construct their own knowledge as they engage in this process. The teacher does not provide the answers but skillfully guides the students in their knowledge construction by providing the activities in which the knowledge construction can occur. The teacher should be a master in asking the appropriate questions to motivate students in the reflective cognition necessary to construct the desired knowledge. Through this constructive process, the student ultimately comes to "own" the knowledge rather than just "renting" it until the exam is completed (Brooks & Brooks).

Teaching for constructivist learning presents more challenges than direct instruction. In order for preservice teachers to better understand and appreciate the benefits of this constructivist pedagogy in mathematics education classes, one approach might be to engage them in anchoring examples of such pedagogy. An anchoring example is one that clearly illustrates a target concept that is not well understood or misunderstood. The example discussed previously (Fusaro, n.d.) to illustrate the associative property and its usefulness could be considered as an anchoring example. An anchoring example is often analogous to the target situation, as in the Fusaro example, and can thus also be referred to as an analogy.

The use of analogies and their success in teaching a new concept, in better understanding a previously taught concept, and in overcoming misconceptions has been well documented (Brown & Clement, 1989; Clement, 1987; English, 1997, 2004; Gentner, 1989; Goswami, 1992; Vosniadou & Ortony, 1989). Clement was the originator of using anchoring example analogies to successfully overcome misconceptions in physics where other methods had limited success. One of the authors of this research adopted the use of anchoring examples in successfully overcoming misconceptions in the area of probability (Fast, 1997, 1999, 2001, 2007) with both high school students and preservice teachers in various educational settings including Canada, the United States, and Zimbabwe. The belief that this approach might also be successful with preservice elementary school teachers in better understanding both elementary mathematics content and pedagogy was well grounded in previous successes.

The essence of success in using an anchoring example in making a connection between that which is not well understood, the target situation, and that which is well known, the anchoring example, is that the anchoring example must be well understood by the student for it to be an anchor. In previous studies conducted by the one of the authors, it was shown that for the analogical approach to be effective, the student having the misconception must be confident that the anchoring example is mathematically correct and that the anchoring example is clearly analogous to the target example (Fast, 1997, 1999, 2001, 2007). Therefore, it is paramount in making a convincing case for anchoring example-based constructivism as a best practice approach to teaching mathematics that the anchoring examples themselves are well understood and are already a part of the students' constructed knowledge.

The Problem and the Research Questions

The mathematics education instructors at the university where this research was conducted became increasingly aware that although the students in their mathematics education courses had taken two or three mathematics content courses, their expectations of the students' mathematics knowledge specific to teaching and the reality of that knowledge were somewhat disparate. These differences between students' actual knowledge and instructors' expectations of that knowledge needed to be identified and resolved for the constructivist pedagogy using mathematics content examples to be effective. Realizing and identifying such differences during the instruction process was inadvisable. The instructors noted that it created frustration in the students and disruption in accomplishing the primary objectives of the lesson. Also, because many students were extremely reluctant to volunteer

answers to mathematics content questions and would rarely acknowledge their confusion and uncertainty orally for fear of being "wrong," it was virtually impossible to accurately assess students' mathematics content understanding through their oral responses in class. Many of the students had previously experienced humiliating circumstances in their encounters with mathematics as revealed by a mathematics attitude survey the instructors had them complete at the beginning of the semester. At least two-thirds of the students' attitudes, and the experiences that led to these attitudes, could be categorized as negative.

With these considerations and the prior research on the importance of mathematics content knowledge specific to effective mathematics pedagogy, particularly in terms of using mathematics content anchoring examples to develop a deeper understanding of the mathematics and how to teach it effectively, this study was designed to answer the following questions:

1. Can intentional instruction in content anchoring examples for various mathematics topics in an elementary mathematics education course result in significant gains in mathematics content knowledge required specifically for understanding the constructivist pedagogy required for teaching those topics?
2. What is the impact on understanding pedagogy, and the time available for its instruction, when providing mathematics content instruction as needed immediately prior to instruction in pedagogy utilizing that content?
3. Can students in an elementary mathematics education course acquire significantly greater confidence in the mathematically correct knowledge they have acquired?
4. How do students in such a course perceive the reasonableness of being required to possess the mathematics content knowledge required for the anchoring examples?
5. What correlations exist between students' content knowledge, confidence, and perceived reasonableness of required content?

Methodology

In conducting the research, the elementary mathematics education course was carefully analyzed to determine the mathematics content knowledge required to understand the pedagogy anchoring examples utilizing this knowledge. A pretest was prepared to assess students' understanding of that mathematics content. Reliability was addressed by using pairs of similar test items to assess understanding of the same concept. When the initial version of the pretest was complete, it was pilot-tested for clarity and validity by three education instructors, three mathematics instructors, and a group of 15 students. Based on these findings, the final version of the pretest was prepared and used for assessing the students in the elementary mathematics education course (see Appendix for sample test items).

The pretest was administered during the first class of the semester to all the students in the two sections of the elementary mathematics education course being offered at the time. Students self-selected enrollment into either section. The Experimental group contained 28 students and the Control group contained 35 students. The Experimental group may have had fewer students because of the day and time it was offered, Friday mornings at 8:00. The Experimental group received revised instruction as in the description that follows while the Control group was taught in the usual manner.

In each pretest item, students were first given an opportunity to demonstrate their understanding of the mathematics concept it contained by responding to a multiple-choice question. They were then also given an opportunity to indicate how confident they were that their responses were correct. Finally they were also asked their opinions of the reasonableness of such knowledge being expected of them in the class they were presently taking. The pretest contained 50 such items that included the major mathematics content knowledge specific to the mathematics pedagogy expected for the education course.

After analyzing the pretest results, part of each class period for the remainder of the semester was utilized to instruct the Experimental group of students in the mathematics content in the pretest questions. Groups of two or three students were asked to participate in this endeavor as one of their assignments. Each group was asked to conference with the instructor regarding the instructional approach of their assigned mathematics concept. In this manner, mathematics content knowledge and understanding of constructivist mathematics pedagogy were both developed in the same assignment. The mathematics content instruction was thus shared by the students and the Experimental group instructor. The Control group was taught mathematics pedagogy by another instructor in the usual manner with no special emphasis being given to the mathematics content knowledge assessed in the pretest.

Following are some examples that were utilized with the Experimental group to anchor the mathematics content and the constructivist pedagogy desirable for its instruction.

Two of the questions on the pretest required knowledge of the relationship between the circumference of a circle and its diameter. Traditionally, instruction on this topic might just involve giving students the formula expressing this relationship. They might then be given a series of questions where they would substitute given numerical quantities for the radius or diameter into the formula and calculate the circumference. This instruction only provided procedural understanding but very little, if any, conceptual understanding. Also, the formula might soon be forgotten, as the instructors in this study discovered when teaching the mathematics education classes. A substantial number of the preservice teachers did not possess the knowledge of the relationship of a circle's circumference to its diameter (some could not remember and quite a few thought it was πr^2).

To anchor this content knowledge and the constructivist pedagogy desirable for its instruction, the Experimental group instructor involved the students in a number of anchoring activities similar to the activities the preservice teachers would hopefully use themselves when teaching their own students. One such activity involved an experiment where students used a discovery approach to conclude that the circumference of circle is about 3.14 times the diameter through measuring the circumferences and diameters of a number of circular objects, recording these measurements in a table, observing the pattern, and formulating a conclusion using inductive reasoning. This constructivist approach utilizing inductive reasoning is strongly advocated by the NCTM Standards (NCTM, 2000) because it is generally more meaningful to younger students than deductive reasoning and proof. Also, the inductive approach is more akin to how we form conclusions in everyday life in "out-of-school" situations.

Another anchoring activity for developing the concept of the relationship between the circumference of a circle and its diameter originated with one of the pretest items itself (see item #18 on the pretest in the Appendix). The class was taken outside and asked to form a circle and its diameter by fully extending their arms horizontally and joining hands. The class had to divide itself in the correct ratio so that all the students were utilized in forming the circumference of the circle and its diameter. This meant that the students had to divide themselves in the ratio of approximately 3 : 1. If students did not realize this prior to the activity, the formation of the circle and its diameter through trial and error would reveal this relationship. The physical activity of creating a concrete circle representation of the relationship between a circle's circumference and its diameter served as a powerful anchoring example in understanding and remembering this relationship and how to teach it. If questions should arise in the future about this relationship, students would likely remember it if the teacher would remind them of the time they went outside to create a circle with their bodies.

"Representations" is one of the NCTM Standards (NCTM, 2000). The particular representation of a situation can be the determining factor whether students understand the mathematics concept involved in a situation. An example used in the mathematics education course to anchor the Representation Standard focused on fraction division. A scenario would be presented in which the instructor desired to utilize a coin-operated car wash that only takes quarters and realizing that he only possessed 3 quarters. The class would conclude that more money was required so the instructor would ask to "borrow" a $5 bill from one of the students. The instructor now wondered aloud whether the amount of money he had for the car wash would be enough. He would hold up the $5 bill and the 3 quarters to the class and ask for the total number of quarters he now had for the car wash, if he changed the $5 bill into quarters.

Invariably, everyone in the class could answer this question, and the instructor would ask if middle school students would also be able to answer the question. The class generally concluded that most would. The instructor would also ask how they solved the problem and the common response was that because there are 4 quarters in a dollar, you just multiply the $5 by 4 which results in 20 quarters, plus the 3 you already have makes 23. The instructor then posed the question, "What is $5\ {}^{3}/_{4} \div {}^{1}/_{4}$?" A majority of the students in the class agreed that representing the question like this was not only more difficult for them but would also invariably be more challenging for middle school students. Some could not remember how to perform the division using the standard procedure. Prior to this research, one course instructor discovered that in trying to use the real-world example, some students did not understand that the car wash situation

Table 1
Experimental and Control Group Results

	Experimental Group ($N = 28$)				Control Group ($N = 35$)			
	Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Knowledge	30.1	5.96	41.0	6.8	27.3	6.36	28.7	6.58
Confidence	139.3	26.9	169.5	28.0	133.7	31.6	159.0	26.2
Directional knowledge confidence	52.3	37.9	120.0	48.5	32.4	42.0	39.0	45.5
Reasonableness	167.4	25.3	168.8	28.2	150.3	31.7	163.7	30.4

and the division computation were analogous and that they represented the same concept and produced the same answer. Consequently, the mathematics education focus on desirable pedagogy was short-circuited by inadequate mathematics content knowledge.

Another anchoring example from geometry that was used by the Experimental group mathematics education instructor required knowledge of the Pythagorean Theorem and the specific Pythagorean triple 3-4-5. In the example, the instructor mentioned an actual discussion with a carpenter who had the mistaken belief that he "never could do math." Nevertheless, he was using the knowledge of the 3-4-5 triangle being a right triangle in ensuring that the walls of the buildings he was constructing were "square" or at right angles to each other. This carpenter was delighted to learn that he was utilizing mathematics knowledge. Informing him that this was in fact the Pythagorean Theorem was especially intriguing to him. He now was keen to know what other mathematics he was unknowingly using.

Connections between mathematics and everyday life are not always obvious, and teachers are now being encouraged to help students make these connections to better realize the value of mathematics as well as to make the mathematics itself more meaningful (NCTM, 2000). In using this example prior to the intentional integration of mathematics content to anchor the importance of connecting the mathematics to everyday life, the instructor realized that some students did not know the mathematics content itself, that is, that a 3-4-5 triangle is a right triangle according to the Pythagorean Theorem. Not knowing the mathematics content diminished the power of the example in making the case for using connections when teaching mathematics. Intentional integration of the Pythagorean Theorem using various anchoring examples like this prior to instruction in pedagogy was designed to help students better understand the pedagogy.

At the end of the semester, a posttest, similar item by item to the pretest, was prepared and administered to both the Experimental and Control groups. Changes in the students' understanding of the mathematics content, their confidence in that understanding, as well as changes in their attitudes toward the reasonableness of knowing that content were assessed. Finally, the intervention effect on pedagogy was assessed in terms of students' understanding of effective methods and the time available for its instruction.

The Findings

Mathematics Content Knowledge

On the pretest, the Experimental group had a mathematics content knowledge mean score of 30.1 out of 50 or 60.3% correct, whereas the Control group had a mean score of 27.3 out of 50 or 54.6% (see Table 1).

On the posttest, the Experimental group improved their mean score to 82.0% correct, whereas the Control group scored 57.4%. The Experimental group showed a significant improvement ($p < .001$) in mathematics content knowledge, but the Control group did not ($p = .06$).[1] Also, the effect size d, for the Experimental Group, was 1.98, which Cohen (1988) designated as a large effect, whereas the Control group

Table 2
Topic Category Scores

	Experimental Group					Control Group				
	Pretest		Posttest			Pretest		Posttest		
	M	*SD*	*M*	*SD*	Δ*M*	*M*	*SD*	*M*	*SD*	Δ*M*
Large Numbers	.66	.36	.95	.16	.29	.71	.31	.74	.33	.03
Number Systems	.48	.28	.79	.30	.31	.47	.27	.43	.31	−.04
Number Operations	.59	.21	.84	.17	.25	.51	.18	.50	.21	−.01
Fractions	.69	.20	.81	.22	.12	.64	.22	.69	.27	.05
Decimals	.75	.35	.82	.13	.07	.67	.36	.76	.31	.09
Percent	.70	.34	.93	.18	.23	.56	.38	.71	.33	.15
Integers	.79	.29	.82	.24	.03	.79	.30	.77	.31	−.02
Proportion	.64	.33	.86	.23	.22	.54	.31	.73	.34	.19
Geometry	.52	.19	.80	.18	.28	.45	.21	.59	.18	.14
Statistics	.82	.24	.91	.20	.09	.73	.39	.67	.30	−.06
Probability	.38	.28	.79	.22	.41	.34	.24	.43	.28	.09
Algebra	.94	.13	.70	.28	−.24	.91	.15	.46	.30	−.45
Measurement	.59	.39	.70	.34	.11	.39	.37	.43	.25	.04

effect size was only .02, which is designated as a small effect.

The 50 questions on both tests were divided into 13 topics for instruction and analysis purposes (see Table 2).

The number of questions for each topic was not the same but dependent on the weight given to the topic in the K-8 state standards (Wisconsin Department of Public Instruction, 1998) where the study was conducted. Also, greater emphasis was given to those topics where students in previous classes had exhibited the most difficulty. The topic of geometry contained the most questions with 14, followed by whole number operations with 8 questions. Improvements in mean scores from the pretest to the posttest were observed in almost all the topics for the Experimental group with the greatest improvements being observed in the categories of Probability, Number Systems, Large Numbers, Geometry, and Whole Number Operations, with each topic showing a positive change of at least 25 percentage points. The mean improvements for the Experimental group were greater than the Control group means in every mathematics topic. The Control group also made substantial improvements in geometry and proportions. The reason for the substantial improvement in these topics when this was not the case in other topics is not clear.

Pedagogical Understanding and Time Available for Its Instruction

The increased mathematics content knowledge and confidence that students gained through prior intentional instruction of mathematics content specific to pedagogy for instruction of that content allowed the instruction in constructivist pedagogy using anchoring mathematics content examples to proceed at an increased rate. In essence, the instructor of the Experimental group was able to complete, in the regularly allotted time, the usual instruction in pedagogy, including all the activities and assignments normally done, as well as provide the students with instruction in the mathematics content that helped them to better understand the pedagogy under discussion. Continuous and final assessment of pedagogy showed the Experimental group performing as well or better than

previous groups of students the Experimental group instructor had taught.

Confidence

Students were also required to rate their confidence that their answers for the mathematics content knowledge items were correct on a scale from "0" to "4" with 0 indicating 0% confidence and 4 indicating 100% confidence. As the Pretest and Posttest each contained 50 items, the total confidence score for each student could range from 0 to 200 on each test. The Experimental group had a mean Pretest confidence score of 139.3 and a Posttest score of 169.5 for a significant improvement in confidence ($p < .001$). The Control group had a mean Pretest confidence score of 133.7 and a mean Posttest score of 159.0 (Table 1) that also represented a significant improvement ($p < .001$). The Experimental group, however, exhibited a significantly greater confidence improvement ($p = .035$) than the Control group.

Considering the effect size statistic for the gain in confidence, the Experimental group exhibited a large effect with $d = 1.06$, while the Control group showed a medium to large effect with $d = .71$.

A directional knowledge confidence score was also calculated for each student. To determine this measure, a mathematics content knowledge item answered correctly was scored as +1, whereas an item answered incorrectly was scored as −1. This knowledge score of +1 or −1 was then multiplied by its confidence score for the corresponding item. For example, if a student exhibited correct mathematics content knowledge on an item (seored as +1) and was 75% confident (scored as 3) that the knowledge exhibited was indeed correct, then the student would obtain a (+1 × 3) or +3 for a directional knowledge confidence score on that item. However, if the student exhibited incorrect mathematics knowledge with the same level of confidence, the directional knowledge confidence score would be (−1 × 3) or −3. Thus, a student's total directional knowledge confidence score could range from −200 to +200.

On the Pretest, the mean directional knowledge confidence score was 52.3 for the Experimcntal group with scores ranging from −21 to +157. These results improved to a mean score of 120.0 on the Posttest with scores ranging from +4 to +185. The Control group scored a mean of 32.4 in directional knowledge confidence on the Pretest and 39.0 on the Posttest. The range of scores for this group was −49 to 148 on the Pretest and −61 to +130 on the Posttest.

A paired two-tailed *t*-test indicated that the directional knowledge confidence scores showed a significant improvement ($p < .001$) from the Pretest to the Posttest for the Experimental group. The Control group, however, did not show a significant improvement ($p = .23$) from the Pretest to the Posttest in their directional knowledge confidence scores.

The effect size for directional knowledge confidence gain also supported the *t*-test results with the Experimental group again showing a large effect size with $d = 1.91$ while the Control group exhibited a small effect.

Reasonableness

Students were also asked to rate the reasonableness of expecting them to be able to answer each mathematics content knowledge question correctly. The reasonableness scale extended from "totally unreasonable" that was scored as "0" to "totally reasonable," which was scored as "4" with demarcations on the scale for the intermediate scores of 1, 2, and 3. Thus, a student's total reasonableness score could range from 0 to 200. The Experimental group obtained a mean reasonableness score of 167.4 on the Pretest and 168.8 on the Posttest, whereas the Control group obtained mean scores of 150.3 and 163.7, respectively (see Table 1). The reasonableness change from the Pretest to the Posttest was not significant ($p = .81$) for the Experimental group, but it was significant ($p = .02$) for the Control group. The difference in the change between the two groups, however, was not significant ($p = .25$).

The effect size for the perceived reasonableness of the knowledge questions was small to medium ($d = .29$) for the Experimental group. The Control group exhibited a small effect size ($d = .11$).

Correlation Between Knowledge, Confidence, and Reasonableness

Tests were also conducted to assess the correlations between knowledge and confidence, between knowledge and reasonableness, and between confidence and reasonableness. None of these correlations was particularly high for either group, but the highest correlations were obtained between confidence and reasonableness with Pearson's correlation coefficient $r = .58$ for the Experimental group and .47 for the Control group.

Discussion, Conclusions, and Implications

Prior to this research, the elementary mathematics education course instructors involved in the study often experienced a disconnect between the students

and themselves in utilizing a constructivist approach. The greatest problem seemed to be the students' lack of confidence in their own mathematical knowledge and in their ability to construct this knowledge. When students volunteered answers, the responses were often prefaced with the comment "I don't know if this is right, but. . . . " The Pretest developed for this study provided the mathematics content knowledge assessment necessary to modify the course for the Experimental group so that they not only were better able to understand the constructivist mathematics pedagogy being advocated but that they also were better able to construct mathematics content knowledge and gain greater confidence in that knowledge.

The results of the intervention in the Experimental group, intentional integration of mathematics content instruction and pedagogy, utilizing the content to anchor the pedagogy, were highly encouraging. As indicated in the Findings section, the Experimental group's Posttest mean mathematics content knowledge score improved significantly on the Pretest, whereas the Control group did not show significant gains. This indicated that the intervention made a significant impact with the Experimental group that did not exist in the Control group where intentional mathematics content instruction was not given.

It is not surprising that the Experimental group achieved significant gains in mathematics content knowledge because they received intentional instruction in mathematics, whereas the Control group only received such instruction incidentally and concurrently with instruction in pedagogy as the Control group instructor deemed necessary. However, it is surprising and noteworthy that the Experimental group was able to achieve these gains without adversely affecting the time available for effective instruction in pedagogy. That is, the Experimental group instructor reported that they were able to proceed at a much quicker pace in pedagogical instruction when the students already understood the content in the mathematics examples used to anchor the pedagogy.

Furthermore, pretesting students to determine their knowledge of the mathematics content that the instructor intended to utilize in the course, and then instructing students where deficiencies existed, prior to the instruction in pedagogy utilizing this knowledge was beneficial in lessening students' frustrations and mathematics phobia throughout the course. This was observable on a daily basis by the Experimental group instructor. The Experimental group instructor considered the intentional integration of instruction in mathematics content with pedagogy to be a success and planned to continue this approach in the future.

In considering changes in mathematics content knowledge for the various mathematics topics, the only topic where the mean score decreased from the Pretest to the Posttest for both groups was Algebra. This occurred primarily because an Algebra question in the Posttest was more difficult than the corresponding question in the Pretest because of an oversight in the pilot- testing. The Control group, however, did not show the same level of improvement in the other topics as the Experimental group. The Control group actually exhibited slight negative changes from the Pretest to the Posttest in four topics besides "Algebra" with minimal positive changes in most of the remaining topics. Disregarding "Algebra," the Experimental group showed a greater improvement for each topic than the Control group, which suggested that the intentional mathematics content instruction was beneficial for all topics.

Both groups showed a significant gain in confidence from the Pretest to the Posttest, but again the Experimental group showed a significantly greater gain than the Control group. Additionally, as described in the Findings section, a directional knowledge confidence score was calculated for each student with confidence in correct knowledge being desirable but confidence in incorrect answers being undesirable. Students who have strongly held misconceptions, that is, they are very confident in their mathematically incorrect knowledge, are highly resistant to change in their thinking and consequently pose a considerable challenge for the teacher. A student who answers a mathematics content knowledge question incorrectly and is just guessing (0% confidence) is more likely to construct the correct knowledge with instruction than a student who answers incorrectly and has 100% confidence in that incorrect answer (Fast, 2001). Thus, it is desirable for a student to obtain a positive directional knowledge confidence score on each item, but even a score of 0 is better than a negative score.[2] Any change in the positive direction is desirable even if the change is from highly negative to less negative. The directional knowledge confidence score was developed and utilized by one of the authors of this study in previous research (Fast, 1997, 1999, 2001, 2007) to provide additional relevant evidence of change that would not be evident from a confidence score change in itself.

The Experimental group also made a highly significant gain in directional knowledge confidence, whereas the Control group's gain was not a significant change. Furthermore, there were students in the Control group who showed a negative change in their directional knowledge confidence from the Pretest to the Posttest, whereas in the Experimental group there were only positive changes. This directional knowledge confidence measure thus indicated a highly desirable result of the intervention for the Experimental group.

The mean reasonableness score for the Experimental group showed only a slight nonsignificant change from the Pretest to the Posttest when the *t*-test was used, whereas the Control group did show a greater change which was significant. One would suppose that after instruction in mathematics content, it would have been the Experimental group that showed a reasonableness gain rather than the Control group, which did not receive any intentional instruction. However, when the effect size statistic was used to determine reasonableness changes, the Experimental group did exhibit a greater effect change than the Control group.

The effect size statistic generally supported the *t*-test results in determining significance in gains for the four dependent variables, namely knowledge, confidence, directional knowledge confidence, and reasonableness. The Experimental group showed a large effect size for the first three variables, whereas the Control group showed a large effect only for confidence, and small effect size for the other three variables.

Also, it is interesting that for both groups, the greatest correlation occurred between students' opinions of reasonableness of mathematics content knowledge expectations and their confidence that their responses to the mathematics content knowledge questions were correct rather than between reasonableness and actually obtaining the correct answers, which exhibited the lowest correlation coefficient. Furthermore, there was a low correlation between obtaining the correct mathematics knowledge answers and confidence that the answers were indeed correct. This supports the authors' experiences that many students rely heavily on external authorities such as the teacher or an answer book to confirm the correctness of their mathematics content knowledge. The students appear to have limited confidence in their own abilities to make that judgment.

The implications of this study point to the necessity of intentional integration of mathematics content with pedagogy for elementary preservice teachers. The careful selection of appropriate mathematics content examples to anchor both a mathematics concept and desirable pedagogy for its instruction appears to have considerable benefits. These benefits include a deeper understanding of the mathematics concept itself, a better understanding of how to teach it, greater confidence in the both content knowledge and pedagogy, and a more positive attitude toward mathematics. Detractors of an integrated approach often mention time availability as an obstacle. This study, however, showed that this is not an issue.

As in previous studies (Fast, 1997, 1999, 2001, 2007), the selection of effective anchoring examples is a key to the success of this approach. Elementary mathematics teachers need time and practice discerning and creating these anchors. Experimentation to determine which anchoring examples are most effective with their own students is also necessary. This becomes part of the action research in which teachers actively engage for their own professional development. The findings could contribute to the further research required on how elementary teachers can better use an integrated approach to teach mathematics. This study suggests, however, that in a college mathematics education course, intentional integration of mathematics content anchoring examples required to understand the mathematics, and the specific pedagogy desirable for its instruction, has considerable benefits.

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Authors' Notes

[1] Two-tailed *t*-tests, paired and nonpaired, as appropriate, were utilized to determine significant differences between means in each of the reported findings.

[2] See Findings section, Confidence subsection, for an explanation of the directional knowledge confidence score and its calculation.

Appendix

Pretest Directions and Sample Items

Mathematics Knowledge Pre-Assessment

For each item, choose the best response by circling your choice. Calculators are not allowed. Then indicate how confident you are by circling your confidence level. 0% means you are just guessing while 100% means you are sure your answer is correct.

Finally, on the line, circle the x that best indicates how reasonable it is to be expected to be able to answer the mathematics question correctly.

10. When the length and width of a rectangle are both doubled, its area is

a) doubled b) halved c) the same d) tripled e) quadrupled

My confidence level that my answer is correct is

a) 0% b) 25% c) 50% d) 75% e) 100%

Expecting me to be able to answer this mathematics question correctly is

totally unreasonable totally reasonable

x_____x_____x_____x_____x

(In order to save space, the confidence and reasonablenessa spects of the questions have been omitted in the Appendix on the remaining questions.)

11. In the multiplication table starting from 1×1 and going up to 9×9, there are

a) more odd products than even products b) more even products than odd products c) all the natural numbers from 1 to 81 d) certain products that appear five times e) none of these.

12. Sally spent $60 at a restaurant. This included the cost of the meal and a 25% tip. The cost of the meal was

a) $15 b) $45 c) $48 d) $75 e) none of these

16. The number of millions contained in one billion is

a) 10 b) 100 c) 1000 d) 10000 e) 100000

18. A class has 29 students. The teacher takes them outside, asks them to hold hands, space themselves equally, and form a circle and its diameter. If all 29 students are involved, with some standing to make the circumference and the remainder to make the diameter, the number of students making up the circumference should be

a) 5 b) 10 c) 19 d) 22 e) 25

22. A rectangle has a perimeter of 100 m. Its largest possible area is

a) 40 sq. m b) 100 sq. m c) 225 sq. m

d) 625 sq. m e) none of these

24. On a 5-question true-false exam, the probability of guessing all answers correct is

a) 5(1/2) b) 1/2 c) 1/5 d) 1/10 e) 1/32

25. $225 \div 25 =$

a) $(200 \div 25) + (25 \div 25)$ b) $(100 \div 25) + (100 \div 25) + (25 \div 25)$

c) $(125 \div 25) + (100 \div 25)$ d) all of these e) none of these

29. $294 - 147 =$

a) $(300 - 150) - 6 + 3$ b) $(300 - 150) - 6 - 3$

c) $(300 - 150) + 6 + 3$

d) $(300 - 150) + 6 - 3$ e) none of these

30. $(4\ ^1/_2) \times (4\ ^1/_2) =$

a) $(4 \times 4) + (1/2 \times 1/2)$ b) $4 \times (4\ ^1/_2)$ c) $(4 \times 4) \times 1/2 \times 1/2$

d) $(4 \times 4) + (4 \times 1/2) + (1/2 \times 4) + (1/2 \times 1/2)$ e) none of these

37. If the Mean (Average) of four scores is 72 and three of the scores are 74, 70, and 67, then the fourth score must be

a) $70\ ^1/_3$ b) 70.75 c) 72 d) 77 e) 87

39. One million divided by 365000 is

a) 0.365 b) somewhat less than 3 c) somewhat greater than 3

d) somewhat less the 3000 e) somewhat greater than 3000

40. A photograph's width is increased from 4 inches to 6 inches. In order to retain the correct proportions of the image, the length should be increased from 6 inches to

a) 7 inches b) 8 inches c) 9 inches d) 10 inches e) none of these

41. Papa Pete's has a pizza special where you can order a large pizza with two *different* toppings for $9.99. If they have seven toppings from which to choose, the number of different ways you could order the special is

a) 6 b) 7 c) 21 d) 42 e) 49

42. A carpenter is building a 6 m by 8 m rectangular fence. He wants to make sure that adjacent sides of the fence are at right angles to each other. To do this, he measures the diagonal of the rectangle he is creating. The length of this diagonal will have to be

a) 6 m b) 8 m c) 9 m d) 10 m e) $\sqrt{28}$ m

44. If three children share $8\ ^1/_2$ cupcakes equally, the number of cupcakes each child gets is

a) 6/17 b) $2\ ^1/_6$ c) $2\ ^5/_6$ d) $25\ ^1/_2$ e) none of these

49. A circle with a circumference of 44 m would have an approximate area of

a) 14 sq m b) 28 sq m c) 69 sq m

d) 154 sq m e) 616 sq m

A Teacher's Conception of Communication in Geometry Proofs

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Mathematical proof has many purposes, one of which is communication of the reasoning behind a mathematical insight. Research on teachers' views of the role that proof plays as mathematical communication has been limited. This study describes how one teacher conceptualized proof communication during two units on proof (coordinate geometry proofs and Euclidean proofs). Based on classroom observations, the teacher's conceptualization of communication in written proofs is recorded in four categories: audience, clarity, organization, and structure. The results indicate differences within all four categories in the way the idea of communication is discussed by the teacher. Implications for future studies include attention to teachers' beliefs about learning mathematics in the process of understanding teachers' conceptions of proof as a means of mathematical communication.

Within the discipline of mathematics, mathematical proof is an essential tool in understanding the mathematical thinking and reasoning used in the development of new concepts. Simply, proofs communicate arguments for new concepts. In terms of school mathematics, mathematical proof is defined as "a formal way of expressing particular kinds of reasoning and justification" (National Council of Teachers of Mathematics [NCTM], 2000, p. 56). Multiple types of mathematical proof provide forms of communication for thinking and reasoning through logical deductive proof (including induction and proof by cases), defined as a finite sequence of formulae or propositions derived from axioms on the basis of establishing rules (Hanna & Jehnke, 1993), indirect proof whereby a contradiction is found when the negation of a conjecture has been made (Williams, 1979), and proof by exhaustion in a finite situation (Maher & Martino, 1996).

Mathematical proof serves many purposes. One of the main goals of proving in mathematics is to demonstrate that a conjecture is valid as well as providing an explanation into why the conjecture is true (Bell, 1976; Hersh, 1993). Others have discussed various purposes of proof to include systematization, discovery, and communication (de Villiers, 1999; Hanna, 2000; Hanna & Jehnke, 1993; Schoenfeld, 1992). Systematization focuses on the organizational features of proof in an axiomatic system, which helps one to avoid errors in logic and to obtain a framework for investigating ideas. Discovery pertains to the invention of new results through proof, often missing in traditional two-column proofs in secondary school where the focus is on the use of logic (Wu, 1996). Communication refers to the transmission of ideas, both in discourse and in writing, of socially constructed knowledge (Cobb, Boufi, McLain, & Whitenack, 1997; Ernest, 1991; Lampert, 1990).

Proof plays a critical role in communicating mathematical knowledge in ways that are considered acceptable to a mathematical community. In the creation of mathematical knowledge among mathematicians, proofs exist through human creativity and imagination, during the preparation prior to proving, as well as during periods of incubation and social interaction (Sriraman, 2004). While logical thought plays an important role in the consistency of mathematical knowledge, human creativity propels mathematicians to reason connections like those between coexisting systems (i.e., algebraic and spatial geometry systems). Thus, it is not uncommon for mathematicians to seek out other mathematicians from other fields to share not only new definitions and theorems, but also research perspectives and philosophies (Burton, 1999; Hersh, 1997).

As a tool for communication, the social aspect of mathematical proof in the classroom is vital in understanding what counts as justification in a community of learners. Students must be taught to understand the reasoning used in proofs as well as the importance and reason for engaging in the development of proofs. The social aspect of the classroom is important in the development of these ideas. Communication has been a central theme in the reform of mathematics classrooms due to its role in facilitating learning through discourse (Cazden, 2001; Knuth & Peressini, 2001). Mathematical communication involves language. Thus, mathematics can be viewed through its

structure, syntax, and cultural meaning (Pimm, 1987). The act of interacting with other students while communicating in the mathematics classroom has been described as "organizing and consolidating ideas, thinking coherently and clearly, analyzing and evaluating strategies, and expressing ideas precisely" (NCTM, 2000, p. 60) and aligns with Pimm's conception of the language of mathematics. Such interactions in the classroom where students are communicating and defending their proofs are essential for the development of a more rigorous understanding of the nature of proof.

Communication must be viewed as both an instructional idea and a mathematical idea. With the importance of communication in the mathematics classroom, a focus on communication through mathematical proof is imperative. This exploratory investigation illustrates how one teacher conceptualized and implemented proof communication through two units on proof (coordinate geometry proofs and Euclidean geometry proofs). While communication is an important aspect of the mathematics classroom at all levels and all topics, these data were taken from a larger study on students' views of the purposes of proof that included explanation, verification, communication, systematization, and discovery.

Theoretical Perspectives

The theoretical framework for this study utilizes both general and specific communicative aspects of mathematical proof. In a general sense, the notion of communication in the mathematics classroom encompasses issues related to literacy through reading and writing mathematics (Pimm, 1987; Thompson & Chappell, 2007). These general communicative aspects are advocated by NCTM (2000) as a way to promote active engagement of students in the learning process.

Social constructivist theory provides a means for understanding specifically the role of communication in mathematical proof in the classroom and within the discipline of mathematics itself (Cobb et al., 1997; Ernest, 1991; Lampert, 1990; Yackel & Cobb, 1996). In the classroom, social and sociomathematical norms play an important role in forming students' views of what it means to understand mathematics and mathematical justification (Yackel & Cobb). Sociomathematical norms are the collective actions and interactions in the classroom that define what is expected during mathematical interactions. Sociomathematical norms could also be what counts as "mathematically different, mathematically sophisticated, mathematically efficient, and mathematically elegant" (Yackel & Cobb, p. 3). Lampert's description of a fifth-grade mathematics classroom illustrates various sociomathematical norms that were established to help students come to know mathematical argumentation as a process in the discipline of mathematics as well as a product. In an epistemological sense, proof plays an important role in the creation of mathematical knowledge. Mathematical proof is the mechanism that transforms individual knowledge (subjective) into public knowledge (objective) through shared meanings and acceptable mathematical justifications (Ernest). In the classroom, mathematical proof can be viewed as a transmission of knowledge or as a collection of shared meanings.

Engaging students in learning about the nature and importance of proof has long been an instructional challenge for teachers. Researchers have documented high school students' lack of ability to produce algebraic and geometric proofs (Healy & Hoyles, 2000; Kahan, 1999; Senk, 1985) as well as their lack of understanding that once a generalization has been proven, no further proof for specific cases is required (Fischbein & Kedem, 1982; Healy & Hoyles; Kahan; Porteous, 1991; Schoenfeld, 1988; Vinner, 1983). In addition, students' understanding of the purposes of mathematical proof has been explored by many (Balacheff, 1988; Bell, 1976; Chazan, 1993; Galbraith, 1981; Healy & Hoyles). The majority of this body of research has shown a lack in students' attention to viewing mathematical proofs as a way to verify conjectures and explain why a conjecture is true even with explicit instructional attention to these aspects.

Much of the research on preservice and inservice teachers' understandings of mathematical proof focuses on teachers' ability to judge the quality of various proofs (Harel & Sowder, 1998; Martin & Harel, 1989; Simon & Blume, 1996). However, Knuth's (2002a) examination of secondary teachers' views of the purposes of mathematical proofs reveals that teachers recognized various roles of mathematical proof, yet are limited with regards to how proofs are used to understand mathematical concepts. In terms of communication, Knuth describes the teachers' views of proof communication as a socioconstructed argument in that "proof arises from, or is a product of social interaction" (p. 390). Further, Knuth (2002b) found that teachers value proof—in an instructional

context—for its role in the development of logical thinking, but that they generally do not feel proof is central to learning mathematics. Dickerson and Doerr (2008) also found secondary mathematics teachers' beliefs about the purpose of proof in schools focus on students' development of critical thinking skills and on students' ability to transfer those skills to other areas of their lives.

While reform curricula have called for a de-emphasis on the use of two-column proof formats for formal proofs, two-column formats remain included on high-stakes testing. Historically, the two-column proof format was introduced in the late 1800s geometry curriculum in order to bring "stability" to the geometry curriculum and to make it easy for teachers to check the validity of proof tasks given to the students in geometry (Herbst, 2002a). Herbst (2002b) illustrated the constraints with using two-column proof in the classroom by illustrating how the ideas used to understand situations can be at odds with the production of the proof itself when using the two-column format. Weiss, Herbst, and Chen (2009) found differences among secondary mathematics teachers' views regarding two-column proof construction. Teachers were shown a videotaped episode of a teacher who encouraged a student to proceed with a proof even though an assumption had not yet been shown true. Some teachers believe that the two-column proof format is a constraint in the process of proving while others see it as a valuable tool in helping students identify the location of missing assumptions.

Several previous studies have interviewed teachers on their conceptions of proof but have not followed those ideas in the classroom instruction. This case study investigation provides an in-depth description of one teacher's conception of proof communication in a natural classroom setting in order to tease out how the teacher supports and encourages the communication and social interaction during the development of the ideas of proof and its importance for the mathematics discipline. Two research questions guided this study:

1. How does a classroom teacher describe communication during two units on proof?
2. How are the sociocultural aspects of mathematical proof addressed during the two units?

Method

Participants

This case study involved one classroom teacher, Mrs. Kelly (a pseudonym). Mrs. Kelly taught high school mathematics for eight years at the same public school in rural New York. Mrs. Kelly's geometry classroom consisted of 19 students; 15 were participants and 4 were nonparticipants. The 15 participants in the study were 5 male and 10 female students. Twelve of the participants were sophomores. One participant was a freshman and two were juniors. Pseudonyms were given to all of the participants to ensure confidentiality. All of the students had previously been exposed to basic algebra, basic geometry concepts, right triangle trigonometry, probability and statistics, and elementary logic (such as basic truth tables). In this classroom, proof was taught without experimentation or exploration and as tasks in proof units. Dynamic geometry software was available in a computer laboratory, but Mrs. Kelly chose not to use the software due to time constraints in the curriculum. Mrs. Kelly worked through several proof tasks with the students through teacher-led instruction before giving students time to work in small groups.

Design of the Study

The data for this study were collected through observation in a naturalistic setting (Moschkovich & Brenner, 2000). In this naturalistic paradigm, a holistic view was taken regarding the teacher's and researcher's constructions within the context of the learning situation in the geometry classes (Lincoln & Guba, 1985). The study was conducted over a period of approximately four months. Fifteen classroom sessions were observed over two instructional units (coordinate geometry and Euclidean geometry). The coordinate geometry proofs were proofs involving specific cases only while the Euclidean proofs involved general situations of triangle congruence using the traditional two-column format. All of the sessions were audio-taped and transcribed by the researcher on a daily basis along with condensed field notes. In addition, informal interviews with the classroom teacher were conducted on occasion.

Data Analysis

The data were analyzed in two stages. First, the transcriptions of the classroom observations were read multiple times by the researcher with the intent of a combination of analyses for identifying themes within the purposes of proof categories: analytic induction, constant comparison, and typology (Huberman & Miles, 2000). Thus, both external and internal coding schemes were employed to assure the validity of the analysis. Data were initially coded according to the five purposes of proof (explanation, verification,

Table 1
A Comparison of Aspects of Communication in Two Proof Units

	Coordinate Geometry	Euclidean Geometry
Audience	Someone who knows almost as much as you do.	The teacher.
Clarity	Summary paragraphs should be written clearly. Calculations should be labeled.	Students should not skip steps.
Organization	Consolidate the calculations with the explanations within the same paragraph.	More organized than coordinate geometry proofs. Consolidate logical statements to make a single statement.
Structure	Paragraphs in plain English. Write for understanding.	Use conditional statements.

communication, systematization, and discovery). Then, within the communication category, four themes were created. Thus, the teacher's conceptions of communication in proof were framed around four features: audience, clarity, organization, and structure. Second, transcriptions and established categories were read again and analyzed by examining the sociocultural aspects of the classroom. A description of the instruction relating to the classroom teacher's communication spanning the two units on proofs involving geometry was identified. The first unit on coordinate geometry proof was conducted over a two-week period, and was followed by a two-week unit on Euclidean geometry proofs.

Results

The following results provide a snapshot of Mrs. Kelly's conceptions of proof communication during two proof units. An overview of the aspects of communication for each of the units is given in Table 1. Aspects of communication in proofs were made explicit during the introductory remarks to the students about "raising the standard" on communication skills for the coordinate geometry proof unit and continued as a constant theme throughout the unit. This expectation was not the case for the Euclidean geometry unit. Communication as a purpose of proof was stressed in the beginning (after formal logic and the axiomatic system) and at the end of the unit.

Audience

In written communication, transactional writing is a form of writing that takes into account the audience (Rose, 1989). In classrooms, the audience is typically the teacher or other classmates. The classroom teacher, Mrs. Kelly, utilized the notion of audience for teaching students how to write proofs in both units, explicitly for coordinate geometry proofs and implicitly for Euclidean geometry proofs. On the first day of the unit on coordinate geometry, Mrs. Kelly wanted her students to imagine that they were communicating to a fictitious audience. The audience she described was that of a younger student who knew some mathematics:

> Pretend that you are explaining to, not really to someone in your class, but explaining to someone a couple of years younger than you. Not someone in kindergarten, but someone who has a basic understanding of the math that you are doing, but maybe not all of it, maybe not as much as you know.

The notion of a fictitious younger audience was used in an introductory problem that asked students to prove quadrilateral ABCD was a rectangle, where A (0, 2), B (8, 0), C (9, 4), and D (1, 6). Mrs. Kelly focused the students' attention to slopes and then reminded students of their fictitious audience by saying, "Here's the part where we have to explain. You have to explain to a seventh or eighth grader."

During the unit on Euclidean geometry proofs, no mention of the audience was explicitly identified. However, Mrs. Kelly made several implicit references to herself as the audience. Mrs. Kelly encouraged students to communicate directly to her:

> And, this one, you don't have to write me an if–then statement. You're going to tell me you did substitution . . . Just tell me which property you did.

During both units, Mrs. Kelly also often put herself in the role of the student, pretending to be the person communicating to an external reader. For example, during the coordinate geometry unit when students were given the coordinates of a quadrilateral and asked to prove it was a parallelogram and a rhombus, Mrs. Kelly assisted the students in determining the appropriate formulas to complete the task, beginning with the distance formula. She followed with a reminder that one of the purposes of proof was communication by stating, "Communicate to your reader. I'm going to start with side AB, so I'm going to tell my reader that." In another instance during the coordinate geometry unit, Mrs. Kelly reminded students to be considerate of the "reader" and even changed her voice as if she was pretending to be an anonymous reader stating:

> So, now a reader would go over and look, "yeah, they did have equal lengths," they are congruent, making DRAW isosceles. A little longer summary than we've had, but there were three different parts we had to talk about too.

Clarity

Writing mathematics with clarity was a goal in both units, yet clarity was described differently for the particular tasks in the different units. In the coordinate geometry proofs, Mrs. Kelly showed a sample of a former student's work to illustrate a clearly written summary. After reading aloud the former student's summary, Mrs. Kelly remarked, "Simple, direct, very straightforward." She also remarked about the labels—M and N—this student created by finding the midpoints of two different line segments, but told the students it was not a requirement for them to label points that they found through calculations. When students worked together in small groups on another proof, Mrs. Kelly emphasized the importance of being "good communicators" and reminded students to label the calculation with the letters of existing sides whose distance was being calculated.

During the Euclidean proof unit, Mrs. Kelly's main concern regarding clarity with two-column proofs was the lack of flow of ideas evidenced by skipped steps:

> I was worried about the first one having you skip some steps, which has been a problem on a lot of our proofs anyway. Because there are things that, your brain, you've got to remember, is so incredibly fast and you are jumping from one little piece of information, you're zipping through about three or four steps you know in your heart that something's true, but that's what we are trying to do. We are trying to get you to slow down, communicate to us about all those individual steps.

Organization

Mrs. Kelly viewed both types of proofs as organizational tools. In the introduction of coordinate geometry proofs, students were told to organize their ideas in two paragraphs. Students were told to show calculations in one paragraph and to summarize in the second paragraph:

> Basically we are going to ask you to complete a task and you are going to do that in two steps. First, you are going to show the work that's necessary for the tasks. That will be the formula, the theorems and calculating that out. Then, the second step you are going to write a summary statement that basically explains how your work completes the task.

Euclidean geometry proofs were organized in a traditional two-column format. When Mrs. Kelly compared the structure of the two kinds of proofs, she explained that two-column proofs would be more organized. On the chalkboard, she wrote and underlined the words *Statements* and *Reasons*. Underneath these two titles, she put "what you know is true" and "how you know it is true," respectively. She informed the students that each of the items in the proof was going to be itemized and numbered.

Students were also encouraged to consolidate their ideas in proofs differently between the two units. For coordinate geometry proofs, Mrs. Kelly let students know that combining the calculations with the summary portions of the proof was acceptable:

> So, we have to do two different things. Now how you write your summary statement is totally up to you. You can write just one summary statement for part *a*, and just be done with it, and then write a separate summary statement for part *b*. Or, you are welcomed to combine the two into one.

However, for Euclidean proofs, consolidation of ideas meant that students could join logical statements together in order to move through a proof:

> Let's start with the rectangle. And, just like I did yesterday with the parallelogram, I'm going to write these out in an if–then form. So, when you are looking for a tool, when you are looking for a reason, and you're stuck on how to word it, this is how you can word it. You can adjust it accordingly to fit your particular proof . . . So if you already have that it is a parallelogram, and we are going to start using conjunctions now, and it has one right angle, then you can say it is a rectangle.

Structure

The structure of the proofs refers to the nature of the sentences used in the proofs by students. In the coordinate geometry proofs, students were encouraged to use normal English language rather than formal mathematical statements (or no statements at all as typically done with an equation). Students were given three formulas (midpoint, distance, and slope) and one theorem (the Pythagorean theorem) to use exclusively throughout the coordinate geometry proof unit. Mrs. Kelly explained to students that English sentences should be used in the summary portion of the coordinate geometry proofs:

> I mentioned communication skills. You are going to have to do some writing, some explaining. We aren't talking about three-page papers here; we are talking about little paragraphs or sentences. But it will be in the English language and fairly grammatically correct. I won't take off points for that but it shouldn't be hard to understand what you are trying to say.

An example of the type of language Mrs. Kelly expected for coordinate geometry proofs was the following: A rectangle and a rhombus *make* a square.

In the Euclidean geometry unit, Mrs. Kelly began the unit by reviewing conditional statements and encouraged students to use them as much as possible. However, Mrs. Kelly also told students that they could express their ideas in their own words if they were unable to recite a theorem. Mrs. Kelly revealed during an interview that she encouraged the use of conditional statements over everyday language in two-column proofs because she believed students were more successful in proof writing when using conditional statements.

Sociocultural Aspects of the Classroom

In both units, Mrs. Kelly relied heavily on modeling proof construction to students. Contributive communication best describes the interaction between the teacher and her students during whole and small group interactions, whereby the conversations were limited to "assistance or sharing" (Brendefur & Frykholm, 2000, p. 127). In coordinate geometry proofs, Mrs. Kelly often described relationships, such as parallel lines or congruent lengths, and then asked students what calculations were needed to show the relationship. In Euclidean geometry proofs, Mrs. Kelly focused on getting students to identify concepts such as betweenness, bisector, and perpendicularity.

For both proof units, Mrs. Kelly encouraged alternative ways to prove tasks. Plans for proving were decided upon by the teacher in whole group instruction, yet students were told to decide on a plan for themselves during small group work. During whole group instruction, once a plan was chosen, no deviations were made. During small group work, Mrs. Kelly remained neutral in having students decide on a plan, yet guided students when they were having trouble implementing their plans. After a certain allotted time (about 15–20 minutes), Mrs. Kelly chose a plan and then the class reconstructed the proof together as she did during whole group instruction. At times, Mrs. Kelly modeled her evaluation of proofs, which focused mainly on the correctness of students' identification of assumptions and reasoning as well as efficiency in proof writing. She often discussed how to write proofs more efficiently. She mentioned that having to re-create algebraic statements was acceptable but that remembering certain theorems saved steps in the proof.

Mrs. Kelly referred often to the formulas and previously proven theorems as tools in a toolbox. She attempted to discuss all of the theorems that students might need in constructing proofs for homework. Coordinate geometry proofs required a finite number of tools while Euclidean proofs sometimes required the generation of additional theorems:

> So, we are just going to add those two together, two of (angle) BOC and two of (angle) AOB. And this is kind of one of those ones that the stuff in our toolbox doesn't really fit. So, think about what you did. All I did was combine, sort of, "like

terms" there, but they're not exactly like terms. But, we know what we mean.

In the creation of additional statements, Mrs. Kelly told students that they would be able to know when to create new statements with additional practice and experience.

The tasks chosen for both units focused on preparing students for the state assessment. In the coordinate geometry unit, most of the tasks focused on proving that the coordinates formed a particular shape. A few of the tasks led to properties of figures (e.g., the median to the hypotenuse is one-half the hypotenuse). Generalizations of these types of tasks were not discussed but were to be done in the following school year. Since the Euclidean geometry proofs focused mainly on triangle congruency, students' experiences with proving more useful theorems were limited.

Students' Conceptions of Proof Communication

Students were given a questionnaire on the purposes of proof after both units on proofs had been completed. One of the items on the questionnaire focused on communication in proof and asked the following: In the mathematics classroom, students communicate with each other and with their teacher all the time about mathematics in many different ways. How is proving a statement in geometry a way of communicating?

The results indicated that students fell into two main categories. The majority of the students surveyed viewed communication in proof as a one-way activity while the other group viewed communication in proofs as an exchange of ideas (see Table 2).

In the first group, students did not seem to make a distinction between proof communication and communication when solving a mathematical problem. For these students, geometry proofs are solved rather than written. The second group seemed to refer to the sociocultural view of proof communication as an agreement between the student and the teacher.

Discussion and Conclusion

Proof communication was valued and viewed in different ways by the teacher in this study. Mrs. Kelly's attention to the audience was unique to the coordinate geometry proof unit. From the beginning, students were encouraged to pretend that they were writing to students who were slightly younger and less knowledgeable. This approach was not used when writing Euclidean proofs, where students were encouraged to communicate directly to the teacher through more structured sentences using conditional statements. Mrs. Kelly's attention to the audience seemed to be based on proof type (coordinate vs. Euclidean) rather than on the sophistication of the reader (Dickerson, 2006).

The differences in Mrs. Kelly's views of clarity and organization between the two units suggested that students needed to be more careful in expressing statements precisely in coordinate geometry proofs and that statements in Euclidean geometry proofs were inherently more precise because of the use of conditional statements. Mrs. Kelly was explicit during both proof units as to what constituted efficiency in proofs. Her views seemed to suggest that clarity and organization play an important role writing an efficient proof. Mrs. Kelly also showed differences in the way ideas should be consolidated. In coordinate geometry proofs, students were allowed to intertwine the algebraic statements with the supporting reasons. In Euclidean geometry proofs, students were encouraged to keep the statement and reasons separate from each other and to consolidate statements by re-stating reasons to encompass a larger range of ideas. Perhaps the more important of the two notions of consolidation is students' ability to consolidate within statements due to its relationship with formal reasoning and logic, since more advanced mathematics requires students to fully understand this relationship (Epp, 2003).

From classroom observations, it was apparent that Mrs. Kelly relied heavily on modeling for teaching mathematical proofs. Using a teacher-directed instructional style, Mrs. Kelly reinforced the notion of external authority in deciding the validity of proofs constructed by the students. By attempting to give students all of the possible theorems students might need in constructing a proof, Mrs. Kelly also reinforced the notion that proofs are constructed linearly, and that all of the pieces, for the most part, should be readily available. When Mrs. Kelly showed students where additional theorems needed to be created, she did so in a way that seemed to minimize social negotiation in understanding what was being created. While it is possible that Mrs. Kelly believed social negotiation of meanings was not needed, it is also likely that curriculum restraints prohibited a deeper exploration of theorems.

Writing proofs efficiently also seemed to be an important aspect of proof writing for Mrs. Kelly. She stressed the importance of simple and direct

Table 2
Students' Responses to a Journal Question about Communication

Category	Response
Demonstration of Understanding	Proving a statement is saying you understand something (most of the time). (Cathy, Grade 11)
	Showing how much you know about geometry. (Jeremy, Grade 10)
	It is a way of explaining the work to another person or teacher. (Ken, Grade 10)
	You're showing what you're thinking and why you're thinking it so when people look at them they know what was going through your mind when you were trying to solve it. (Kim, Grade 9)
	Trying to prove a statement help shows your teacher where your best skills are, your weak skills are in proving geometry. She then sees where you need help. (Marty, Grade 10)
	It's a way of communicating because when you are proving something, you are telling someone and explaining how to do something, or why something is a certain way. A proof is a way for people to explain things, I guess. (Penny, Grade 10)
	If the teacher gives a problem, the student answers it. That's just like asking a person a question and the person answering it. (Seth, Grade 10)
	Proving a statement in geometry is a way of communicating because you're giving a statement and a reason and that reflects what you know about the problem. (Sue, Grade 10)
	You have to state something and give proof to explain it. (Mackenzie, Grade 10)
Proof is an exchange of ideas	You explain your way of reasoning and both the teacher and the student communicate until they agree. Also, when you write down all of your steps to the proof you are communicating about how you got your answers. (Betty, Grade 10)
	You have to talk and inquire it; it's all of what you think or part of it. So you have to get what other people are thinking to get the full statement. (Brandi, Grade 10)
	It's a way of communicating because you are using words and sentences to prove something is true with asking questions and receiving answers. (Nikki, Grade 10)
	It's showing each other's ways of solving things, maybe helping others to solve the problem. (Kara, Grade 10)
Other	It's proving that a statement is true or a theorem. (Lori, Grade 10)
	No response. (Eric, Grade 11)

approaches. Unfortunately, Mrs. Kelly was not interviewed about efficiency in proofs, which makes it difficult to say that Mrs. Kelly was trying to establish a sociomathematical norm. She may have held the belief that her students would be more successful in writing proofs had they used simple and direct approaches, as she indicated when discussing the use of conditional statements.

The results of this study warrant two limitations to the understanding of teachers' conceptions of proof communication. First, the proof tasks that were selected during the instructional units did not pertain to the creation of new mathematical knowledge for students. As Herbst (2002a) pointed out, researchers have questioned the legitimacy of teaching proof in isolation from concept development, such as in the

teaching of Euclidean geometry proofs. The proof tasks in Euclidean geometry engaged students in understanding the relational knowledge of geometric concepts rather than to engage students in constructing knowledge. Coordinate geometry proof tasks had the potential for connecting proof and knowing, but they were not pursued. As Knuth (2002b) noted, teachers' conceptions of proof play an important role in the tasks that are selected. While the many differences in Mrs. Kelly's conception of proof communication described in this study support Knuth's findings, proof communication was limited to two specific proof contexts.

Second, little was known regarding how the teacher generally perceived mathematical proof. More information about Mrs. Kelly's beliefs about learning mathematics and her views of the curriculum was needed to better understand her views about proof communication. It is possible that Mrs. Kelly's beliefs about mathematical learning may have influenced several of her conceptions of proof communication for the various tasks as indicated with the use of conditional statements in two-column proofs. As students begin to learn about communicating through proofs, teachers need to be aware of their beliefs, their own conceptions regarding proof communication, and how they might influence students' perceptions of mathematical proofs. It is also possible that Mrs. Kelly held somewhat naïve views of proof communication. She seemed to link communication directly with writing in paragraph form while communication was not explicitly linked to the two-column form. Teachers need to clearly recognize the importance of mathematical communication in order to support a classroom culture that focuses on students' development of mathematical communication in proofs. Thus, future examinations of teachers' conceptions of proof communication should consider the relationships among the task, curriculum, and teachers' beliefs about mathematical learning.

As a case study, the explicit and implicit conversations about communication during the proofs units given by the teacher (as well as the students' views about proof communication) are unique to this particular classroom. Nevertheless, the study indicates more research on mathematical communication is needed. For example, more research is needed regarding teachers' conceptions of communication in proofs and justifications through other mathematical contexts. For example, how do teachers perceive communication in proofs involving algebra concepts? How do teachers approach vocabulary and symbolism as communicative tools in algebraic proofs? Since many mathematics curricula call for the integration of topics, studies involving teachers' conceptions of proof communication that connect topics such as algebra, geometry, and probability would also be a valuable addition to the area of research on communication.

In a call for increased mathematical literacy, Thompson and Chappell (2007) highlight the need for teachers to be well-versed in all areas of communication (speaking, listening, writing, and reading) to help students develop a "robust understanding of mathematics and develop fluency with all aspects of language" (p. 190). Future research should examine more closely teachers' use on consolidating statements and how teachers facilitate students' thinking within this context. While this investigation focused on written communication only, it would be worthwhile to also investigate teachers' perspectives of proof communication in the classroom through a more integrative approach involving all areas of communication.

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Re-creating a Recipe for Science Instructional Programs: Adding Learning Progressions, Scaffolding, and a Dash of Reading Variety

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The purpose of this article is to focus on the development and refinement of a science instructional design program arguing for the feasibility and usability of integrated reading and science instruction as implemented in third- and fourth-grade science classrooms to meet the learning needs of diverse learners. These instructional components are easily inserted into existing programs that build students' science background knowledge and abilities to apply learning through scaffolded activities focused on (1) providing structured opportunities for students to engage in hands-on activities; (2) increasing vocabulary knowledge and understanding of concept-laden terms, and (3) reading paired narrative and informational science texts. Extensive research shows that as students transition from third to fourth grade and beyond, they are often challenged in science by new vocabulary coupled with new concepts. Active ingredients of our reconceptualized science instructional design program are narrative informational texts, hands-on science activities, and science textbook(s).

> At no time in history has improving science education been more important than it is today. Major policy debates about such topics as cloning, the potential of alternative fuels, and the use of biometric information to fight terrorism require a scientifically informed citizenry as never before in the nation's history. (Duschl, Schweingruber, & Shouse, 2007, p. 1)

Science curriculum and standards in the United States have been portrayed as "a mile wide and an inch deep" (Center for Science, Mathematics, and Engineering Education, 2000, p. 135). Science teaching in most classrooms reflects either a nonparticipatory or a myopic view of science learning, that is, students read the adopted science textbook, complete worksheets or other formulistic writing assignments, and occasionally complete verification labs. Opportunities for meaningful applications of the integrated use of everyday representational resources (talk, reading, writing, multimodal representations, and multiple representations) (Wallace, Hand, & Prain, 2004) are not present. This ultimately leads to classrooms that are impoverished in inquiry and conceptual learning (O'Sullivan & Weiss, 1999). Not only is this picture of instruction bleak, the tools of teaching (e.g., textbooks, ancillary/supplementary materials, assessment instruments) lack the means to guide and inform teachers on how to build on students' prior knowledge, to contextualize science in relevant problems, and to appreciate and richly represent complex ideas other than in a superficial manner (Kesidou & Roseman, 2002; Schmidt, Houang, & Cogan, 2002; Schmidt, Wang, & McKnight, 2005).

As noted by Duschl and his colleagues (2007), there is an urgent need to evaluate and reconceptualize the way that science is taught in most U.S. classrooms. As they noted, "Science education has been a perennial issue of national concern, and its recent history warrants attention, a stock-taking of the current knowledge base and the prospects for promising directions in the future" (p. 12). We agree. As one places a looking glass over the present science education curriculum, what looms largest is that much of the present-day science education curriculum is built on invalid representations about students' cognitive development and learning, which lead to less than effective teaching of science (Metz, 1997). There is a need for research on the development of fully articulated science instructional programs' that enables today's science teachers to be well prepared in instruction in order to teach science to a student population having great diversity in cultures, backgrounds, interests in social learning, language, and reading abilities (Capraro & Slough, 2008).

We know that what children learn is dependent not only on curriculum and standards, but also by how they are engaged in the science curriculum, those experiences that they have that extend, reinforce, and stimulate them to engage in deeper processing of

scientific concepts. National Assessment of Educational Progress data (Lee, Grigg, & Donahue, 2007) present sobering evidence that almost two-thirds of fourth-grade students cannot read grade-level materials with understanding. These students lack the cognitive capabilities necessary for understanding informational texts. These cognitive skills are prior knowledge required to connect with what is read (Saddler, 2005; Sadoski, 1999), vocabulary knowledge (Baumann, Kame'enui, & Ash, 2003) to understand the concept-laden words esoteric to the subject, and metacognitive skills to monitor learning (Nagy, Berninger, Abbott, Vaughan, & Vermeulen, 2003; Stahl & Fairbanks, 1986).

A compilation of snapshots of classroom science instruction would portray science curriculum and standards as an abstract composition where its interpretation, and thus execution, lies solely in the eyes of the beholder. Teachers strive to interpret and implement this varied composition of a broad yet lean curriculum, and as a result they give woeful attention to students' understanding and put unsubstantiated focus on superficial factual level questions (Weiss & Pasley, 2004; Weiss, Pasley, Smith, Banilower, & Heck, 2003). These chronic and anemic activities in science classrooms have the deleterious effect of misrepresenting science in such an inadequate manner that students are deprived of the opportunities of the fullness of knowing what it means to understand and use science. When the typical science instruction in the intermediate grades can be adequately characterized across the country as reading the textbook, taking notes, writing definitions for vocabulary, and taking tests over factual information; students' perceptions of science is placed within the narrow parameters of recall and recognition of facts. The students' perceptions become reality as the teaching is repeated across the grades—recall of facts on demand, rather than thinking about science as a sense-making activity requiring the use of prior knowledge, analysis, discussions, debates, reformulation, rejections, and confirmation (Carey, 1991; Smith, Wiser, Anderson, & Krajcik, 2006).

For students to fully engage in inquiry, they must fully participate in hands-on activities, they must read, they must negotiate meaning through small and large group discussions, and they must represent their emerging knowledge through the creation of artifacts (e.g., posters, graphs, models, presentations, and reports) (Wallace et al., 2004), but in what duration and sequence? The purpose of this paper is to present an argument for the development and refinement of a science instructional design program integrating reading and science instruction as implemented in third- and fourth-grade science classrooms to meet the learning needs of diverse learners. The design program is illustrated as a learning progression due to the two-year grade band of transitioning from learning-to-read to reading-to-learn (Chall, 1996) (although the principles on which it is designed are applicable to all instruction) and includes three main integrated components: (1) narrative informational texts; (2) sections from traditional science textbooks; and (3) hands-on/minds-on science activities.

How Can They Learn Science if They Cannot Read?

It is well established in the literature that the last part of third grade and the beginning of fourth grade are pivotal times for students' learning (Blair, Rupley, & Nichols, 2007; Chall, 1996; Gersten et al., 2005). Teachers of content areas often fail to recognize that developmentally, these students are moving from a *learning-to-read* curriculum, where the majority of their learning of science is accomplished through doing, seeing, or hearing, to a *reading-to-learn* curriculum, where they are expected to read and learn from informational text (e.g., science text) (Chall). Content-area texts have been labeled "inconsiderate" (Anderson & Armbruster, 1984), "bombardments" of unfamiliar concepts (Harmon, Hedrick, & Wood, 2005), and overwhelmingly vocabulary and conceptually dense (Blachowicz & Fisher, 2000). Because students must understand 90–95% of the words in a text to adequately comprehend (Hirsch, 2003; Nagy, 2005), difficulty in comprehension of science texts can be partially attributed to the high density of unfamiliar vocabulary (Baumann, Edwards, Boland, Olejnik, & Kame'enui, 2003; Biemiller, 2003).

A majority of students have not received sufficient instruction for reading informational text to adequately prepare them for the cognitive tasks this type of reading requires (Duke, 2000). Many students who were previously reading on grade level begin to fall behind and experience difficulty reading informational textbooks; this downturn in performance is often referred to as the "fourth-grade slump" (Chall, Jacobs, & Baldwin, 1990). This "slump" may be the result of many factors; however, there is general agreement that reading for comprehension and learning of

informational texts goes far beyond just recognizing the words (Chall & Jacobs, 2003). Reading capabilities necessary for understanding informational texts are prior knowledge to connect with what is read and learned, vocabulary knowledge (Gardner, 2007) to understand the concept-laden words that are esoteric to the subject, and metacognitive skills to monitor learning (Baumann, Edwards et al., 2003; Nagy, 2005; Stahl & Fairbanks, 1986).

A reader's background knowledge, including purposes, has an overriding influence upon the reader's development of meaning, and reading comprehension involves the activation, focusing, maintaining, and refining of ideas toward developing interpretations that are plausible, interconnected, and complete. In addition, there is a sense in which the reader's comprehension involves two other facets: the reader knowing (either tacitly or consciously) that his or her interpretations for a text are plausible, interconnected, and completely make sense, and, ideally, the reader's evaluation of the transfer value of any acquired understanding. We can view background knowledge as an individual's experiential and cognitive capabilities for (1) written text (word recognition, concept of print, understanding of word order, and understanding of word meanings), as well as for (2) the content of what is being read, and for (3) how text is organized (Alexander & Jetton, 2000). Activating prior knowledge is especially important in science.

Reading to Learn: Vocabulary Is the Key

Continuous development of students' language abilities provides the foundation for vocabulary growth. Students often share meanings of words orally through their direct experiences with people, places, objects, and events that they encounter in their lives. In addition to these direct experiences, students gain vocabulary concepts through vicarious experiences including interactive technology, virtual tours, pictures, movies, reading, and writing (Nichols, Rupley, Blair, & Wood, 2008). Students' knowledge of vocabulary closely reflects the breadth of their real world and vicarious experiences (Heilman, Blair, & Rupley, 2002). Since students' knowledge of vocabulary is dependent upon the experiences of the learner, it would be convenient if the content of the curriculum reflected these experiences (Rupley, Logan, & Nichols, 2003). But as educators know, the variation of the experiences students receive through life's experiences is often at a mismatch with the school's curriculum, and as previously stated, the difference between the number of words that students use and encounter in conversational vocabulary is vastly underproportioned to the academic vocabulary that is required to comprehend content area texts, particularly science, where preciseness of word meaning is paramount to understanding and applying concepts.

Developmentally, most readers by the end of the fourth grade have just accomplished the task of *learning-to-read*, whereas the school curriculum and content areas expect them to be proficient at *reading-to-learn* the more varied forms of expository text, which up to this point were previously not emphasized during the learning-to-read stages (Chall, 1996). Many students have not received sufficient instruction for understanding the vocabulary encountered in expository text to adequately comprehend this type of reading (Freebody & Anderson, 1983; RAND Reading Study Group, 2002). Since vocabulary development is a principal contributor to reading comprehension and is one of the best predictors of reading achievement (Broemmel & Rearden, 2006), the National Institute of Child Health and Human Development (2000) has acknowledged the importance of vocabulary development and instruction (Richek, 2005).

Science vocabulary communicates a degree of preciseness that general language does not (Halliday & Martin, 1993; Yore et al., 2004). For example, in science, *adaptation* refers to a change to suit the environment through the development of physical and behavioral characteristics that enable species to survive and reproduce in their environment; thus, it represents an esoteric meaning. Whereas in general language it can mean several things—*adapting* a book to become a play, *adapting* a dress to fit a particular need or occasion, or *adapting* to a new school, all of which reflect a process of changing that is short term. Furthermore, complex sentence structure and linguistic structures in science are intended to convey information within precise and narrow parameters. Vocabulary that is unfamiliar and language structure that is complex and unique to the discipline of science create sources of potential impediments to learning both the rudimentary concepts and conceptual skills necessary to comprehend and apply scientific principles and understandings (Hand et al., 2003). Teachers of science, knowing that the vocabulary and language processing skills in science content are barriers for many students to experience success in

understanding and actively engaging in learning science content, can thus provide the necessary scaffolding to support their learning (Moje, Collazo, Carrillo, & Marx, 2001). Knowing that students often lack the academic language capabilities to enable their learning from texts, alternative instructional measures that concurrently support learning from linguistically challenging texts are needed (Hand et al.).

Why Are We not Teaching Science Very Well?

There is a need for fully articulated science instructional programs that enables today's science teachers to be well prepared in instruction in order to teach science to a student population having great diversity in cultures, backgrounds, interests in social learning, language, and reading abilities (Capraro & Slough, 2008). We present the conceptualization and implementation of science instruction that integrates the science content, the means for learning, and the accommodation of all students' needs in a research and theoretical sound curriculum set in the context of learning progressions. We chose learning progressions to specifically address the two-year grade band from third to fourth grade as students transition from *learning-to-read* to *reading-to-learn.*

Central findings from *Taking Science to School* (Duschl et al., 2007) were that young children (K–4) knew more about their world than they were given credit for and could do more sophisticated learning than might have been presumed in the past. This was key to their suggestions for developing/mapping learning progressions in science. Learning progressions extend beyond vertically aligned curriculum such as that presented in the *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993) and the *National Science Education Standards* (National Research Council, 1996) such that one can describe/plan the successively more sophisticated ways of learning that can follow and build on one another as children learn about and investigate a smaller number of topics more deeply over a longer span of time (e.g., 6–8 years). Project 2061's *Atlas of Science Literacy* (AAAS, 2001) does provide some initial examination of important science concepts in science, including important connections across concepts and multiple grade spans in K–12, but their organization is more representative of the "structure of the disciplines" (Duschl et al., p. 216) than the needs and abilities of the learners.

Quality instruction entails strategically designing learning progressions such that students' encounters with science that take place in real time and perhaps over a period of months and years (Duschl et al., 2007). Learning within these progressions is constrained by children's prior knowledge and skills and their ability to: (1) know, use, and interpret scientific explanations of the natural world; (2) generate and evaluate scientific evidence and explanations; (3) understand the nature and development of scientific knowledge; (4) participate productively in scientific practices and discourse; and by teachers' knowledge and the effectiveness of their instructional practices (Duschl et al.). This four-strand framework represents an important departure from the false dichotomy of content or process that drives much of current practice in science education today because it provides an alternative that focuses on how students' understanding of a topic can be supported and enhanced from grade to grade. A new emphasis on knowledge, reasoning skills, and scientific practice informs the design of learning progressions, which offers insight into how curricula might be reorganized to better support science learning. This requires that learning be organized around a smaller set of central ideas in science that can be studied and developed in depth and at increasing levels of understanding. Learning progressions should be central to a discipline of science, accessible to students, and have potential for sustained student interaction and engagement.

The clear message from a discussion on learning progressions is that inquiry experiences devoid of meaningful science content and/or teaching content alone are not likely to lead to sustainable science learning (Slough & Milam, 2008). Without authentic experiences in learning communities (Wallace et al., 2004) that focus on how scientific evidence is obtained, evaluated, and accumulated, students are unlikely to connect school science with their own real-world experiences. Students need experiences that go beyond the simplified seven-step version of the scientific method that is often taught in U.S. schools. Duschl and his colleagues (2007) provide a new vision for K–8 science instruction that is based upon the increasingly clear understanding that children come to school with more knowledge of the world around them and that these students are able to comprehend and reason much more effectively than was typically presumed—especially when their previous knowledge

is paired with well-thought-out, long-term experiences informed by the four-strand framework.

Teachers draw upon their knowledge of science, their students, and pedagogy to plan and enact such instruction. Thus, in addition to understanding the science content itself, effective teachers understand learners, apply effective pedagogical designs, and use ongoing assessment (formative) to monitor and adjust students' science learning experiences. The catalyst of such multiple understandings and practices is teachers providing appropriate levels of scaffolding to support the science learning of their students (Wallace et al., 2004).

Scaffolding: Holding Students' Science Learning Together

Scaffolding is teacher support that enables students to do learning activities that by themselves would be too difficult. This support for learning can be gradually taken down and ultimately removed as students become capable of performing the activity, strategy, or behavior on their own. Scaffolding allows teachers to transfer the responsibility for learning to students gradually and still provide expert guidance and varying degrees of support. Pearson and Fielding (1991) discuss the role of scaffolding:

> In scaffolded instruction, the teacher determines the difference between what students can accomplish independently and what they can accomplish with just more expert guidance, and then designs instruction that provides just enough scaffolding for them to be able to participate in tasks that currently are beyond their reach. When scaffolded instruction operates according to plan, two things happen: first, the tasks and texts of the moment gradually come more and more under the learner's control; and second, more difficult tasks and texts become appropriate bases for further teacher-student interaction. (p. 849)

Scaffolding stretches the students to move safely into a level of being moderately uncomfortable in their learning. The effective science teacher is cognizant of how to capitalize upon this stretching to scaffold students' learning through planning, implementing, and evaluating a variety of approaches to teaching science. Children's background experiences vary with their cultural, linguistic, and economic background. For example, cultural differences in discourse patterns are well documented, and some students' standard for discussion and social interaction may actually be at odds with the standards in scientific practice (Moje et al., 2001). Such differences mean that students arrive in the classroom with varying levels of experience with science and varying degrees of comfort. All students bring basic reasoning skills, personal knowledge of the natural world, and curiosity, which can be built on to achieve proficiency in science. Capitalizing on these students' varying entering capabilities requires sensitivity and skill to support students' science learning in light of these differences. Adjusting for variation in students' background and experience does not mean dumbing down the science curriculum or instruction provided to certain groups of students. It means that instructional practices are injected into science instruction that scaffolds the learning of these students.

Scaffolding Science Learning for Students' Diverse Needs

Struggling readers can be students who do posses well-developed word recognition skills, but lack fluency and therefore read too slowly to chunk information into meaningful units of understanding, are limited in a well-developed vocabulary for the content under study, or don't have adequate prior knowledge to connect what they are reading and learning to any meaningful bases of existing knowledge.

What works well for struggling readers will often work well with English Language Learners (ELLs) (Slavin, Lake, & Groff, 2007). Knowledge of the vocabulary that occurs in informational text and the ability to derive word meanings independently are requisites to text comprehension that assume increasingly greater importance as students progress through the grades (Baumann et al., 2003; Cromley & Azevedo, 2007; Graves, 2006). Research evidence has clearly informed us that struggling readers and ELL students experience difficulty comprehending content-area text because of the prevalence of unfamiliar vocabulary and a lack of domain knowledge or conceptual understanding (Biemiller, 2003). These students cannot easily apprehend the meaning of connected text if there are gaps in their understanding of component parts (i.e., individual meaning-bearing words, underlying concepts, implicit relationships) (Chall & Jacobs, 2003).

Many students struggling in reading will need a great deal of scaffolded instruction based on

meaningful practice after the point at which teachers would normally judge that they have mastered the reading skill. Such practice needs to occur at an appropriate level of difficulty, be accomplished with a variety of materials, and be characterized by an interactive teaching style. Additional practice can be supplied through supplemental textbooks, newspapers, magazines, commercial learning kits, literature books, teacher-made materials, games, computers, and various realia (real objects such as maps and word cards). Both teacher-supervised (or guided) and independent practice can be accomplished in a variety of learning groups. Cooperative learning in science promotes more active learning (Slavin et al., 2007; Slavin, Cheung, Groff, & Lake, 2008), with students talking and working together rather than listening passively to the teacher (Wallace et al., 2004). As with any type of cooperative grouping, this arrangement won't be successful without careful preparation . Building upon the theoretical underpinnings of learning progressions and diversity of instructional practices to meet the needs of struggling readers and ELL students, we recommend a combination of the following ingredients that actively scaffold science learning: (1) narrative informational texts; (2) sections from traditional science textbooks; and (3) hands-on/minds-on science activities. But, integrating hands-on science, informational narrative texts, and textbooks in long-term scaffolded learning progressions is significantly more complicated than just picking a few children's literature books that generically match the desired concepts and skillful application.

How to Pick Instructional Strategies

Some programs have combined informational narrative text and textbooks for the primary purpose of improving reading ability, but not acquisition of science concepts. However, as noted by Labbo:

> Trade books that relate to particular content areas offer qualitatively different opportunities for children to construct knowledge than do textbooks. For example, many trade books use the sort of informal language patterns that resonate with children. Specialized vocabulary terms, which frequently are defined formally in textbooks, are often contextualized in descriptions, rich examples, and illustrations in trade books. (1990, para. 1)

Examples of instructional strategies for enhanced context are those that make learning relevant to ELL and struggling readers by presenting material in the context of real-world examples and problems. Teachers provide a myriad of scaffolding by bringing the real world to students through technology, informational narrative texts, hands-on learning, and effective use of science textbooks that relate topics to students' previous experiences or learning and engage students' interest. Collaborative learning as well is a scaffolding component based upon learning organization, such as flexible heterogeneous groupings and group inquiry projects. Support in these conditions of organization for learning affords scaffolds at multiple levels and varying degrees of support. With a decreased emphasis on covering everything in the science textbook it provides struggling learners more time to learn in the best ways for them to learn. ELL and struggling readers are engaged in project-oriented, hands-on activities that require and support multiple and varied opportunities to read, write, and build verbal skills through repetition and collaboration at levels of meaningfulness that accommodate their needs (Capraro & Slough, 2008; Wallace et al., 2004). They receive comparable benefits as they build understanding of key concepts that contribute to enhancing their verbal skills as compared and conceptual knowledge.

Design and Implementation of Reading/Science Instruction to Scaffold ELL and Struggling Reader Learning

Learning Progressions are complex and cannot be simply reduced to a single learning object and accompanying activity or text reading. An example of scaffolded learning through the purposive selection and integration of informational narrative test, hands-on activities, and text are documented in a sample introduction for a grades 3 and 4 Heredity Learning Progression as shown in Tables 1 and 2. This introduction only reflects an introduction, not a full learning progression due to the limited space. Although learning progressions are envisioned as one answer to the overprescribed, shallow curricula in today's high-accountability environment, teachers and students are held accountable to local, state, and national standards. Therefore, our Heredity Learning Progression introduction design is based upon appropriate state standards, in this case the Texas Essential Knowledge and Skills (TEKS) Standards for Science (http://www.tea.state.tx.us/teks/112-001n.htm) (e.g., Learning Progression on Heredity would include TEKS 3.9,

Table 1
Introduction to Heredity Learning Progression

TEKS (State Standards)	Activities	Narrative Text
(3.9) Science concepts. The student knows that *species* have different adaptations that help them *survive* and *reproduce* in their *environment*. The student is expected to: (A) observe and identify *characteristics* among *species* that allow each to *survive* and *reproduce*; and (B) analyze how *adaptive characteristics* help individuals within a *species* to *survive* and *reproduce*.	**Owl pellet dissection.** Students "dissect" the contents of an owl pellet to assemble skeleton(s) of their prey. **Lima bean dissection activity.** Students dissect a lima bean seed and observe the new life within. **Lima bean in a bag.** Students grow and observe a lima bean. **Wisconsin Fast Plants.** Students grow and observe the life cycle from seed to seed in one month. **Same or Different?** Students use photographs of plants and animals to see likenesses and differences in species. All of the above are adaptable to students' needs by varying activities reflective of their existing capabilities—keeping written or pictorial logs, graphing, writing, drawing, discussing, classifying by characteristics (adaptive, survival, reproduction, etc.).	*The Beauty of the Beast* (Prelutsky, 1997). A book of poems about animals (all levels). *Seed is a Promise* (Merrill, 1990). This story compares a seed to a promise because there is the promise of a new plant contained within every seed. *Jungle Eyes* Reading Is Fundamental (RIF) web-based Read Aloud book (expanded description in Table 2)

Table 2
Resources for the Heredity Learning Progression Introduction

The activities are designed to meet state standards (e.g., **TEKS** (Texas Essential Knowledge and Skills): http://ritter.tea.state.tx.us/teks/112toc.htm.

The activities for the Heredity Learning Progression were adapted from the Yale—New Haven Teachers Institute—http://www.yale.edu/ynhti/curriculum/referencelists/elementary/EScience.html and the Science TEKS Toolkit—http://www.utdanacenter.org/sciencetoolkit/instruction/snapshots/3.php.

The narrative text selections include poems and stories and traditional and web-based informational narrative texts, including a Reading is Fundamental (RIF) program selection (http://www.rif.org/assets/Documents/readingplanet/ReadAloud_Stories/jungle_eyes.html) that shows the power of informational narrative text that can be used to scaffold all levels of learner, but especially the struggling reader and ELL students. It is a web-based "read aloud" book, designed so that students can click on parts of the story/pictures and it is read aloud as they read along. This provides multiple inputs (seeing, doing, and hearing), which are so powerful for ELL and struggling readers.

3.10, 4.8, and 4.9). State standards were chosen to illustrate the specificity of designing the instructional intervention across the two grade levels (third and fourth grade) associated with the transition from learning-to-read to reading-to-learn (Chall, 1996).

Teacher Talk to Accompany Heredity Learning Progression

In our example, we begin with a huge emphasis on observations of *species*, *characteristics* (include traits in discussion), *individuals*, *adaptations*, and *environment*. Note that observations include physical experiences, pictures, stories, and poems. Teachers will scaffold utilizing multiple and appropriate strategies the concepts of *survival* and *reproduction*, as they are less observable. Formative assessments that are appropriate at this time include student-generated products such as scientifically accurate poems (Broemmel & Rearden, 2006), oral reports, and science journals (written and/or drawn) that focus on observing, identifying, and analyzing adaptive characteristics for *survival* and *reproduction* and include multiple representations of these concepts (Hand et al., 2003).

Care was taken to include examples of species of plants and animals and examples of informational narrative selections of poems and stories. Students whose vocabulary and linguistic skills are emerging need additional opportunities to expand on their definitions of species and adaptations that go well beyond the ones in the hands-on activities or informational narrative text. They need experiences that allow them to know, use, and interpret scientific explanation; generate and evaluate scientific evidence and explanations; understand the nature and development of scientific knowledge; and participate in scientific practice and discourse. Specific examples that would accommodate such diversity of learners' needs are those that take advantage of varied exposures, multiple representations, and integration of multiple sensory channels, such as a paired word wall with pictures, pictorial sorts, drawings and pictorial representations, written logs, data collection, graphs, and vocabulary maps (see Table 2). Student-directed discussions based on these multiple representations are essential for them to repeatedly encounter science words and to build their science vocabulary and science-precise conceptual knowledge.

Discussion of Introduction to Heredity Learning Progression

Our above introduction and examples to the Heredity Learning Progression are provided as illustrations of how active ingredients meld together to integrate hands-on science and informational narrative text to address specific state-based and curriculum objectives. The objectives were scrutinized for process vocabulary such as observe, identify, and analyze and conceptual vocabulary such as *species*, *characteristics* (include traits in discussion), *individuals*, *adaptations*, *environment*, *survival*, and *reproduction*. Exact activities and informational narrative text were selected so that when paired together they would enhance the achievement of the learning objectives. For instance, owls are a *species*, each different type of prey (seen through different adaptations in their bones, fur, feather, etc.) is a *species*, lima beans are a *species*, and fast plants are a *species*. *Adaptations* are seen in owl pellets, different types of bones, fur, feathers, etc, of the prey, sizes of beans, length of growth cycles, requirements for plant growth, and *reproduction* occurs in the fast plants and not the lima beans.

The first narrative text cited is a wonderful resource for all students in the third and fourth grade because of a wide range of readability levels for the poems and accurate illustrations that help conceptualize the characteristics and descriptions of the animals. The word difficulties vary for each poem so there would be science content appropriate for a struggling reader and repetition of words and concrete referents for an ELL and struggling readers. The book includes poems about reptiles, fish, arthropods, and mammals. Many of the poems are about owls and owl characteristics, which could be used to either introduce students to owls to build background knowledge or to extend existing background knowledge, learn science vocabulary (e.g., owl pellets, nocturnal, predator), and conceptualize and generalize to the *adaptive characteristics* of owls and similar species. Full development of the Learning Progressions would build upon this process to include continued emphasis on creating opportunities for struggling reader and ELL learners to engage in scaffolded, meaningful, and developmentally appropriate learning activities that stress oral language, reading, writing, and content area learning.

Conclusion

Teachers have always discussed, teachers have always read out loud to early readers, students have always read narrative texts, students have always read the textbook, students have always written, and students usually have done hands-on science—what distinguishes effective instruction is the purposive

selection of differentiated informational narrative text with common hands-on experiences, classroom discourse, and textbook-based work (Slough et al., 2010). The implementation of an instructional program that integrates oral language, reading, writing, and science content in ways that are meaningful and developmentally appropriate for all learners enables teachers to address an individual student's needs without large investments in new resources or practices; they just take familiar tools and construct more meaningful science learning for all students.

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Elementary School Teachers' Manipulative Use

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Using data from 503 inservice elementary teachers, this study investigated the relationship between teachers' background characteristics, teachers' beliefs about manipulatives, and the frequency with which teachers use manipulatives as part of their mathematics instruction. Findings from the study show that teachers' grade level and beliefs about manipulatives are important predictors of teachers' use of manipulatives in their mathematics instruction.

Mathematical learning that focuses on understanding is an important goal of school mathematics (National Council of Teachers of Mathematics [NCTM], 2000). As suggested by Hiebert et al. (1997) there are many tools that teachers can use to help students develop mathematical understanding. One such set of tools is physical materials such as base-10 blocks or fraction tiles. These are examples of mathematical manipulatives. In the literature, there is no unique definition for mathematical manipulatives. For example, some definitions describe manipulatives as objects that can be touched, moved about, and rearranged (Kennedy, 1986); other definitions suggest that manipulatives can also be stacked (Clement, 2004); while others, such as Moyer (2001), emphasizes that these objects should represent "explicitly and concretely mathematical ideas that are abstract" (p. 176). Mathematical manipulatives offer students a way of understanding abstract mathematical concepts by enabling them to connect the concepts to more informal concrete ideas.

Even though manipulatives have been proposed as useful tools to help students gain mathematical understanding, teachers differ in how they use manipulatives in their mathematics classrooms (Hatfield, 1994; Howard, Perry, & Tracey, 1997). In education, differences in practices have been related to several factors, such as teachers' beliefs, content knowledge, and attitude (Ernest, 1989; Wilkins, 2008). In relation to teachers' use of manipulatives as part of their instructional practice, studies have focused on teachers' characteristics such as experience (Gilbert & Bush, 1988), grade level (Weiss, 1994), and beliefs (Moyer, 2001); however, these studies considered these factors separately. Therefore, it is not clear if and how these different factors interrelate to influence teachers' use of manipulatives. In this study, we will investigate how teachers' grade level, beliefs about manipulatives, and other background characteristics affect how often elementary school teachers use manipulatives during their mathematics instruction. In addition, this study will examine the interrelationship of these variables as they relate to manipulative use. In particular, this study will consider the following research questions:

1. Is there a relationship between teachers' use of manipulatives and the grade level that they teach?
2. Is there a relationship between teachers' use of manipulatives and teachers' background characteristics (e.g., age, years of experience)?
3. Is there a relationship between teachers' use of manipulatives and their beliefs about manipulatives?
4. How do teachers' grade level, beliefs, and other background characteristics interrelate as predictors of teachers' manipulative use?

Manipulatives in Mathematics Instruction

Even though many teachers and educators support the use of manipulatives (Hiebert et al., 1997; Kennedy, 1986; NCTM, 2000; Suydam & Higgings, 1977), results from studies about the effectiveness of manipulative use are inconclusive. While some studies report that students benefit from using manipulatives in their mathematics lessons (Bolyard, 2005; Clements,1999: Clements & Samara, 2007; Moyer, 2001; Suh, 2005; Suydam, 1984; Suydam & Higgings, 1977; Trespalacios, 2008), others have found an opposite result or no result at all (Drickey, 2006; McClung, 1998; Posadas, 2004; also see Fennema, 1972; Sowell, 1989).

Bain, Lintz, and Word (1989) found that all "effective teachers" in their study—those whose students' achievement was in the top 15%—reported using manipulatives to teach mathematics, and 98% of them

specifically state they use concrete objects in their classrooms. More recently, Clements and Samara (2007) used the *Building Blocks Assessment of Early Mathematics, PreK–K* to evaluate students performance after using "building blocks" software and found that students who used manipulatives outperformed students in the control group.

Moreover, the idea that the use of manipulatives in mathematics classrooms helps students to develop mathematical understanding is supported in the literature (Kennedy, 1986; Reimer & Moyer, 2005). For instance, Kennedy concludes that "[l]earning theories and evidence from research and classroom practice support the use of manipulative materials to help children learn and understand mathematics" (p. 7). In a research study with third-grade students using virtual manipulatives to learn fractions, Reimer and Moyer state that there was a significant improvement in students' conceptual knowledge of fractions after working with the virtual manipulatives.

However, positive results have not always been found. Sowell (1989) and Fennema (1972), using meta-analysis, found several studies that report negative results. In a more recent study, McClung (1998), comparing a group of students using Algeblocks (ETA Cuisenaire, Vernon Hills, IL) to a group of students not using them, found that the students not using the manipulatives scored significantly higher on the posttest than those using the Algeblocks. The teaching method for the nonmanipulative group was "lecture, homework and in-class work sheets" (p. 27), and while the manipulative group was treated similarly, instead of worksheets the students used manipulatives. According to the author, some possible factors affecting the lower results of the manipulative group were the teacher's lack of knowledge about using these tools in their classroom as well as students' lack of familiarization with the devices.

Manipulatives by themselves cannot bring about understanding (Ball, 1992; Baroody, 1989; Kamii, Lewis, & Kirkland, 2001; Viadero, 2007). The importance of using manipulatives is the quality of student's thinking promoted by using them (Kamii et al.), as well as the abstractions that can be reached from the interaction with these objects, as promoted by Piaget (Kohler, 2008). How teachers design their classroom activities involving manipulatives will ultimately affect the success of their use on student understanding.

Teachers' Use of Manipulatives

Results from studies considering manipulative use are varied. One of the reasons for these results could be how teachers use them in their classrooms. Not all teachers use manipulatives, and those who use these tools do not necessarily use them the same way. For example, some teachers use manipulatives more frequently than others. Making decisions related to instructional practice is complex and may be related to several factors such as teachers' content knowledge, beliefs, background characteristics, or attitude (Ernest, 1989; Wilkins, 2008). Factors identified in the literature as affecting how often teachers use manipulatives in their classroom are grade level (Howard et al., 1997; Weiss, 1994), teachers' background characteristics (Gilbert & Bush, 1988; Howard et al.; Opdenakker & Van Damme, 2006), and beliefs (Gilbert & Bush, 1988; Howard et al.; Raphael & Wahlstrom, 1989).

Grade Level

The frequency with which teachers use manipulatives in their classrooms differs between the elementary, middle, and high school levels. Weiss (1994) reported that, in general, the use of manipulatives in mathematics classes increased from the mid-1980's to 1993; however, the frequency with which teachers used manipulatives was found to differ by grade level. Elementary school teachers were found to use manipulatives more often than middle school teachers. High school teachers were found to use manipulatives the least. In addition, Howard et al. (1997), comparing elementary and secondary mathematics school teachers' views of manipulatives in mathematics instruction, found that just 4% of the secondary teachers reported using manipulatives in every lesson, while 55% of their colleagues at the elementary level reported manipulative use in every lesson.

Other studies considering the use of manipulatives at the elementary school level have found further differences between elementary school teachers (Gilbert & Bush, 1988; Howard et al., 1997; Kloosterman & Harty, 1987; Malzahn, 2002; Suydam, 1984). Howard et al. found that manipulative use varied by grade at the elementary school level, with K–4 grade teachers using manipulatives more often than their colleagues in grades 5 and 6. In addition, Malzahn, analyzing national data, reported that the use of manipulatives was different for grades K–2 students and grades 3–5 students. For the K–2 group, it was found that more than 50% of the students used manipulatives in all or

almost all of their mathematics classes, and just 15% of the other group used these tools that often. This finding is consistent with results from Kloosterman and Harty in an investigation of reports from 301 elementary school principals. They found that manipulatives were used more often in grades K–2 classrooms than in grades 3–5 classrooms. In addition, Suydam found that teachers of second grade or higher reported less use of manipulatives than teachers in grades K–1, and use decreased as the grade level increased. Moreover, for primary grade-level teachers, Gilbert and Bush, working with teachers from the first to the third grade, found that the use of manipulatives decreased between teachers in these three grade levels, but they did not report how the three groups of teachers statistically compared to each other across grades.

Based on past research, manipulative use is related to the grade level of the teacher. However, because of inconsistencies in these results, it is possible that there are other teacher characteristics—not controlled for in prior research—that interact with or explain these differences. For example, perhaps teachers who believe that the use of manipulatives is important for children's learning tend to teach in the lower grades and vice versa. In this case, teachers' beliefs influence their choices and not just the elementary curriculum. Instead of just knowing that manipulative use is related to grade, by considering the interrelationship of several teacher variables, in addition to grade level, we may better understand why teachers choose to use manipulatives.

Teacher Background

Teachers' background characteristics have been found to be related to teaching practices (Gilbert & Bush, 1988; Howard et al., 1997; Opdenakker & Van Damme, 2006). Opdenakker and Van Damme found that teachers' characteristics such as classroom management skill and job satisfaction are related to their teaching style. For example, they found that teachers with high job satisfaction tend to give more support to their students, and those with good classroom management skills have good relationships with their students. Specifically considering the use of manipulatives as a teaching practice, several studies have investigated its relationship with elementary school teachers' characteristics (Gilbert & Bush; Howard et al.; Raphael & Wahlstrom, 1989). The results of these studies are mixed. For instance, Gilbert and Bush studied 220 teachers of first, second, and third grades from 12 states in the United States and found that less experienced teachers used manipulatives more often. On the other hand, Raphael and Wahlstrom, using data from 103 eighth-grade teachers in Ontario from the Second International Mathematics Study, found that experienced teachers used manipulatives more often than less experienced teachers. In addition, Howard and colleagues studied 900 elementary and secondary mathematics teachers from the southwestern suburbs of Sydney and the North Coast of New South Wales, and found no relationship between manipulative use and elementary mathematics teaching experience. Moreover, no relationship was found between manipulative use and other teacher characteristics such as gender, position in school, school system, and teacher preparation (Howard et al.).

Teacher Beliefs

Teachers' beliefs about mathematics and mathematics teaching have been identified as an important factor associated with classroom practice (Ernest, 1989; Nespor, 1987; Thompson, 1984, 1992; Wilkins, 2008). For example, Nespor presents an example of a professor who believed that his students would be more interested in the study of math if its applications were addressed in class; therefore, he designed his instruction to incorporate mathematical applications. Thompson (1984) found teachers' beliefs to be an important factor related to teachers' instructional behavior. In her study, she collected data related to teachers' instructional practices through direct observation and data related to teachers' beliefs from individual interviews. Even though not all of the participants showed a direct relationship between mathematics teaching beliefs and teaching practices, the author reported a strong relationship between beliefs about mathematics and teaching practices. In addition, she found that the relationship between beliefs and teaching practices is not a simple one to understand.

Understanding this relationship has been the focus of many studies in mathematics education. For example, Ernest (1989) developed a theoretical model of mathematics teacher's knowledge, attitudes, and beliefs that suggests the complexity of teachers' decision-making process associated with their teaching practices. Wilkins (2008), based on this model, used path analysis in a study of 481 elementary teachers and found teachers' beliefs to be the strongest predictor of teaching practices, among teachers' content knowledge, attitudes, and other background characteristics.

Research specifically considering manipulative use and its relationship to teachers' beliefs has provided inconclusive evidence (Perkkilä, 2003; Suydam, 1986; Moyer, 2001; Howard et al., 1997). For example, in a research report, Suydam (1984) indicates that even though teachers believe manipulatives to be tools that could help students develop meaning in mathematics, second-grade or higher-level teachers do not use manipulatives very often. In addition, Perkkilä, who collected data from six first- and second-grade teachers, found teachers' beliefs about manipulatives and their practices to be inconsistent. Although teachers believed that manipulatives are helpful, there were other factors that led teachers to not use these tools (Perkkilä).

Moreover, teachers hold certain general beliefs about manipulatives and their use. For example, Perkkilä (2003) states that for teachers in their study, "the use of manipulatives in teaching/learning situations was often regarded as useful for promoting the view that 'math is fun' " (p. 3). In a qualitative study of manipulative use, Moyer (2001) found that teachers associated manipulatives with "fun math" and not with "real math," and as a result, in general, they did not use manipulatives for teaching and learning concepts. These findings also suggest that teachers' beliefs and actions, in particular manipulative use, are related.

The Present Study

Mathematical understanding is essential for elementary school students, and manipulatives are tools that teachers can use to help students build understanding. Research suggests several factors that may affect elementary school teachers' use of these devices, in particular the grade level that they are teaching, teachers' background characteristics, and teachers' beliefs. No studies to date have analyzed the interrelationship of these three variables and manipulative use. In the current study, we investigated the relationship between teachers' use of manipulatives in their mathematics instruction and their beliefs about manipulatives, the grade they teach, and teachers' age and teaching experience; further, we investigated the interrelationship among these variables. In this investigation we wanted to answer the following research questions:

1. Is there a relationship between teachers' use of manipulatives and the grade level that they teach?
2. Is there a relationship between teachers' use of manipulatives and teachers' age and years of experience?
3. Is there a relationship between teachers' use of manipulatives and their beliefs about manipulatives?
4. How do teachers' grade level, beliefs and other background characteristics interrelate as predictors of teachers' manipulative use?

Methods

Data

This study analyzed data collected from 530 inservice elementary school teachers from two school districts in the southeastern part of the United States. These teachers were participants in a professional development experience.

Measures

Teachers were asked to complete a survey at the beginning of the professional development experience. The survey contained items related to their beliefs, attitudes, and instructional practices associated with mathematics and mathematics teaching. Three questions on the survey were related to teachers' use of manipulatives in the classroom using the following prompt for each: "In your mathematics lessons, how often do you usually ask students to do each of the following? (1) Use manipulatives to solve exercises or problems; (2) Use manipulatives to explore a concept; and (3) Engage in hands-on mathematical activities." These items were rated on a five-point Likert scale (1 = *Never*, 2 = *Rarely* [a few times a year], 3 = *Sometimes* [once or twice a month], 4 = *Often* [once or twice a week], and 5 = *All or almost all mathematics lessons*). These three items were found to have internal consistency as a single measure of manipulative use (Cronbach's $\alpha = .90$). These items were used to create a MANIPULATIVE variable which was used as an indicator of the frequency with which teachers used manipulatives in their mathematics lessons.

Teacher background characteristics included in this study are age of teachers (AGE) (1 = *under 25*, 2 = *25–29*, 3 = *30–39*, 4 = *40–49*, 5 = *50–59*, and 6 = *60 or more*) and teaching experience (EXPERIENCE) (1 = *0–2 years*, 2 = *3–5 years*, 3 = *6–10 years*, 4 = *11–15 years*, 5 = *16–20 years*, 6 = *21–25 years*, and 7 = *26 or more years*). In order to facilitate interpretation of these two variables (AGE and EXPERIENCE) their values were recoded. Values for the variable AGE were recoded by taking the value in

the middle of the range for each of the options. For the lower endpoint we used a value of 23 and for the upper endpoint we used a value of 62. Therefore the coded values are *23 minimum*, *27*, *35*, *45*, *55*, and *62 maximum*. The values of EXPERIENCE were coded by taking the value in the middle for the first six options and adding two more years to the minimum value of option 7. Then, the new values for EXPERIENCE are *1*, *4*, *8*, *13*, *18*, *23*, and *28*. Teachers' grade level (GRADE) (from 0 = Kindergarten to 5 = Grade 5) was also included as a variable.

Three questions on the survey were related to teachers' beliefs about manipulatives. Two were based on the following prompt: "In your opinion, how important are each of the following for effective mathematics instruction in the grades you teach? (1) Provide concrete experiences before abstract concepts (CONCRETE); (2) Have students participate in appropriate hands-on activities (HANDSON)." These items were rated on a four-point Likert scale (1 = *not important*, 2 = *somewhat important*, 3 = *fairly important*, and 4 = *very important*). Teachers were also asked to indicate their level of agreement with the following item using a six-point Likert scale (1 = *Strongly disagree . . .* 6 = *Strongly agree*): (3) Because older students can reason abstractly, the use of manipulatives becomes less necessary (OLDER).

Results and Discussion

From the total of 530 teachers, 27 of them did not complete all the items from the questionnaire. Teachers with missing items were removed from the sample, resulting in a working sample of 503 teachers. Descriptive statistics for the variables for the teachers are shown in Tables 1 and 2.

To investigate possible differences in teachers' manipulative use by grade level, a one-way analysis of variance (ANOVA) was conducted. The results show that there are significant differences ($F = 48.22$, $p < .05$) in teachers' use of manipulatives by grade. Using a Dunnett's T3 post hoc analysis, we found three grade groups with statistically significant mean

Table 1
Descriptive Statistics

Variable	1	2	3	4	5	6	7	8	*M*	*SD*
1. MANIPULATIVE	—								4.12	.80
2. AGE	−.06	—							40.10	10.73
3. EXPERIENCE	.02	.75**	—						12.45	9.10
4. CONCRETE	.11*	.02	.06	—					3.80	.49
5. HANDSON	.42**	−.04	−.02	.23**	—				3.85	.39
6. OLDER	−.13**	.03	−.01	−.00	−.12**	—			4.64	1.22
7. KINDER	.39**	−.04	−.01	.06	.15**	.01	—		0.20	.40
8. FIRSTSECOND	.22**	−.08	−.05	.02	.10*	.02	−.38**	—	0.36	.48
9. THIRDFIFTH	−.53**	.10*	.06	−.07	−.23**	−.02	−.45**	−.66**	0.44	.50

Note: $N = 503$; * $p < .05$; ** $p < .01$.

Table 2
Means for Manipulative Use by Grade

	Grade					
	K	1	2	3	4	5
MANIPULATIVE	4.73[a]	4.44[b]	4.25[b]	3.82[c]	3.53[c]	3.53[c]
N	102	96	84	76	76	69

Note: Means with same letter are not statistically significant from each other.

differences (see Table 2). The first group is the Kindergarten teachers who were found to use manipulatives most often. The second group consisted of Grades 1–2 teachers, and the third group included Grades 3–5 teachers. Grades 3–5 teachers were found to use manipulatives least often.

In order to consider the relationship between manipulative use and teacher grade, background, and beliefs, a series of regression models were estimated, culminating in a final predictive model including all the variables. Model 1 considered only grade level, allowing us to investigate previous findings related to grade level (e.g., Gilbert & Bush, 1988; Howard et al., 1997; Malzahn, 2002; Suydam, 1984). Based on results from the ANOVA, three dummy-coded variables were created: KINDER for kindergarten teachers, FIRSTSECOND for first and second grade teachers, and THIRDFIFTH for third through fifth grade teachers. The variable FIRSTSECOND was used as the contrast group (i.e., FIRSTSECOND not included in model). The variable MANIPULATIVE was regressed on KINDER and THIRDFIFTH. This first model basically replicates the ANOVA, but allows us to control for the effects of grade in subsequent models.

Model 2 was the background model and MANIPULATIVE was regressed on AGE and EXPERIENCE, and it allowed us to investigate the relationship between those background characteristics and manipulative use and compare it to previous findings (e.g., Gilbert & Bush, 1988; Howard et al., 1997; Raphael & Wahlstrom, 1989). For Model 3, the beliefs model, MANIPULATIVE was regressed on the three teacher beliefs about manipulatives (CONCRETE, OLDER, and HANDSON); this model allows us to investigate the relationship between teachers' beliefs about manipulatives and manipulative use and compare them to previous findings (Howard et al., 1997; Moyer, 2001; Perkkilä, 2003; Suydam, 1988). The final model includes all seven variables, so MANIPULATIVE was regressed on all the variables KINDER, THIRDFIFTH, AGE, EXPERIENCE, CONCRETE, OLDER, and HANDSON. This model extends previous research by investigating the interrelationship among all the variables and MANIPULATIVE, and how each variable is related with MANIPULATIVE while the other variables are controlled in the model. The results of each model are described below.

From Model 1 (see Table 3), as expected from the ANOVA, grade variables explain a significant proportion of variance ($F = 112.54$, $p < .01$) with KINDER ($\beta = .19$, $p < .01$) and THIRDFIFTH ($\beta = -.445$, $p < .01$) statistically different from first–second grade teachers. In addition, as expected, the contrast group—first and second grade teachers' frequency of manipulative use—was in the middle of the other two groups.

From Model 2, AGE ($\beta = -1.61$, $p < .05$) was found to be a statistically significant predictor of manipulative use. According to the results, older teachers, on average, tend to use manipulatives less often than younger teachers. There is also a statistically

Table 3
Standardized Coefficients for Each Regression Model

Variable	Model 1 β	Model 2 β	Model 3 β	Final model β
KINDER	.19***			.17***
THIRDFIFTH	–.45***			–.39***
AGE		–.16*		–.07
EXPERIENCE		.14*		.10[a]
CONCRETE			.02	.00
OLDER			–.08*	–.10**
HANDSON			.40***	.29***
R^2	.31	.01	.18	.41

Note: * $p < .05$; ** $p < .01$; *** $p < .001$; [a] $p = .057$.

significant relationship between EXPERIENCE (β = .14, $p < .05$) and manipulative use. Experienced teachers tend to use manipulatives more often than novice teachers. However, the amount of variance explained by AGE and EXPERIENCE is relatively small, indicating that these background characteristics have very little predictive power in teacher manipulative use.

From Model 3, there is a significant proportion of variance explained by teacher beliefs (F = 36.67, $p < .01$), but just two of the three variables, HANDSON ($\beta = .40, p < .01$) and OLDER ($\beta = -.08, p < .05$), were found to be statistically significant predictors of manipulative use. Based on these results, teachers who believe that it is important for students to participate in appropriate hands-on activities use manipulatives more often than teachers who do not agree with the statement. Also, teachers who do not agree with the statement "Since older students can reason abstractly, the use of the manipulatives becomes less necessary" tend to use manipulatives more often than teachers who agree with it, which suggests that teachers who think that older students do not need manipulatives tend to use manipulatives less often than their colleagues who agree with the statement.

The Final Model, including all seven variables, beliefs about manipulatives (CONCRETE, OLDER and HANDSON), grade variables (KINDER and THIRDFIFTH), and teacher characteristics (AGE and EXPERIENCE), explains a significant proportion of variance in the MANIPULATIVE variable ($F = 49.72$, $p < .01$). In this model, four out of the seven variables were found to be statistically significant predictors of manipulative use. Those variables were OLDER ($\beta = -.10$, $p < .05$), HANDSON ($\beta = .29$, $p < .01$), KINDER ($\beta = .17$, $p < .01$), and THIRDFIFTH ($\beta = -.39, p < .01$). Interaction effects associated with the variables were not found to be statistically significant, and were excluded from the model.

Considering the interrelationship among the variables, while AGE and EXPERIENCE were statistically significant predictors of manipulative use in Model 1, after controlling for grade and beliefs, these variables were no longer statistically significant. Further, while the overall direction of the relationship between KINDER, THIRDFIFTH, OLDER, HANDSON, and MANIPULATIVE remained the same, the magnitude of the coefficients was reduced, indicating possible shared variance among these variables (see Table 3). An examination of the correlations between HANDSON and THIRDFIFTH (see Table 1) finds a statistically significant, although small, negative correlation between these variables, indicating that teachers in grades 3–5 tend not to believe in the importance of having children participate in appropriate hands-on activities. Consistent with this finding is a small positive correlation between HANDSON and KINDER, indicating that teachers in kindergarten tend to believe that it is important for children to participate in hands-on activities. Together these findings suggest that while grade does predict manipulative use, some of the differences may be further due to the beliefs of teachers who choose to teach in these grades.

Conclusion

The aim of this study was to investigate the relationship between teacher grade, beliefs, and other background characteristics, and the interrelationship among these variables, and how often teachers use manipulatives in their mathematics instruction. Results from this study suggest that teachers' beliefs and the grade level that they teach are important predictors of how often elementary school teachers use manipulatives in their mathematics instruction. However, teacher background characteristics were not found to be consistent predictors of manipulative use.

Kindergarten teachers were found to use manipulatives more often than the other grade-level teachers, and teachers in grades 3–5 were found to use manipulatives least often. Further, this relationship does not change when teachers' background characteristics and beliefs were controlled. This result is consistent with previous research showing less use of manipulatives in the higher grades at the elementary school level (Gilbert & Bush, 1988; Howard et al., 1997; Kloosterman & Harty, 1987; Malzahn, 2002). However, results of this study indicate further differences at the primary level as Kindergarten teachers were found to use manipulatives more often than teachers in grades 1–2, which is different from previous research (Howard et al.; Kloosterman & Harty; Malzahn) and provides evidence of a tendency for a decrease in manipulative use between teachers of the first, second and third grades (cf. Gilbert & Bush).

Although teachers' years of classroom experience and age were found to be related to manipulative use when considered alone, after controlling for teacher grade and beliefs these variables were no longer statistically significant predicators of manipulative use.

This finding helps to clarify the mixed findings of previous research (cf. Gilbert & Bush, 1988; Howard et al., 1997; Raphael & Wahlstrom, 1989) and suggests that teacher background characteristics alone do not help explain the important instructional mechanisms that determine teachers' choice to use manipulatives in their classroom. Consistent with results indicating a relationship between teachers' beliefs and their instructional practices (Moyer, 2001; Nespor, 1987; Thompson, 1984, 1992; Wilkins, 2008), teachers' beliefs about manipulative use were found to be related to their use of manipulatives in their mathematics instruction. Teachers who tend to believe that it is important to have students participate in appropriate hands-on activities for effective mathematics instruction tend to use manipulatives more frequently in their mathematics lessons. Further, teachers who tend to believe that the use of manipulatives with older students is less necessary were found to use manipulatives less often. These relationships remained salient even after teachers' background characteristics and grade were controlled.

By considering the interrelationship among previously studied variables related to manipulative use, we were better able to determine those variables that are more likely to add to our understanding of teachers' manipulative use with further study; that is, based on this study, teacher beliefs and teacher grade level. Further study should focus on why grade level makes a difference. For example, there may be grade-level curricular differences that influence the use of manipulatives. However, findings from this study also hint at a relationship between teachers' beliefs and the grade level that they teach. While this study was not able to identify this relationship as a strong one, the evidence suggests a possible avenue for further study to better understand why teachers choose to use manipulatives in their classroom.

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Authors' Note

The data for this study were collected as part of a project funded by National Science Foundation Grant #9911558. Any conclusions stated here are those of the authors and do not necessarily reflect the position of the National Science Foundation.

PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972-86-477-648. Questions concerning proposals and/or solutions can be sent e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before January 15, 2011

• **5128:** *Proposed by Kenneth Korbin, New York, NY*

Find all positive integers less than 1,000 such that the sum of the divisors of each integer is a power of two.

For example, the sum of the divisors of 3 is 2^2, and the sum of the divisors of 7 is 2^3.

• **5129:** *Proposed by Kenneth Korbin, New York, NY*

Given prime number c and positive integers a and b such that $a^2 + b^2 = c^2$, express in terms of a and b the lengths of the legs of the primitive Pythagorean Triangles with hypotenuses c^3 and c^5, respectively.

• **5130:** *Proposed by Michael Brozinsky, Central Islip, NY*

In Cartesianland, where immortal ants live, calculus has not been discovered. A bride and groom start out from $A(-a, 0)$ and $B(b, 0)$, respectively, where $a \neq b$ and $a > 0$ and $b > 0$ and walk at the rate of one unit per second to an altar located at the point P on line $L : y = mx$ such that the time that the first to arrive at P has to wait for the other to arrive is a maximum. Find, without calculus, the locus of P as m varies through all nonzero real numbers.

• **5131:** *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

Let a, b, c be positive real numbers. Prove that

$$\frac{a+b+3c}{3a+3b+2c}+\frac{a+3b+c}{3a+2b+3c}+\frac{3a+b+c}{2a+3b+3c}\geq\frac{15}{8}.$$

• **5132:** *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

Find all all functions $f : C \to C$ such that $f(f(z)) = z^2$ for all $z \in C$.

• **5133:** *Proposed by Ovidiu Furdui, Cluj, Romania*

Let $n \geq 1$ be a natural number. Calculate

$$I_n = \int_0^1 \int_0^1 (x-y)^n dxdy.$$

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SSM Publication Guidelines

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Heather R. Rodriguez, Managing Editor
School Science and Mathematics Journal
Texas A&M University
4232 TAMU Harrington
College Station, TX 77843-4232

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Frequency of issue: 8 times per year
Copies per issue: 3001-4000
Sponsorship: Professional organization

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3. Graphics submitted as publication-ready copy on white background with black type. Each table or figure should be on a separate page at the end of the manuscript, with a note within the ms where the graphic should be placed. Use no smaller than 8-point font for text on figures; use no smaller than 11-point font for tables. Figures and tables should be no wider than 6.75 inches.

Manuscripts submitted for review will be evaluated on the following:

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Relevence, timeliness, and significance
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SCHOOL SCIENCE AND MATHEMATICS

Volume 110 • Number 8 • December 2010

Marygrove College Library
8425 West McNichols Road
Detroit, MI 48221

SSMA Official Journal of the School Science and Mathematics Association, Founded 1901

School Science and Mathematics

Journal Office

(All publication matters except advertising and reprints)

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School Science and Mathematics (Print ISSN: 0036-6803, Online ISSN: 1949-8594) is published in January, February, March, April, September, October, November and December on behalf of the School Science and Mathematics Association by Wiley Subscription Services, Inc., a Wiley Company, 111 River St., Hoboken, NJ, 07030-5774. Periodical postage paid at Hoboken, NJ and additional offices.

Postmaster: Send all address changes to *School Science and Mathematics*, Journal Customer Services, John Wiley & Sons, Inc., 350 Main St., Malden, MA 02148-5020.

Information for Subscribers: *School Science and Mathematics* is published in eight issues per year. Subscription prices for 2010 are: Institutional Print & Online rate: US$250 (the Americas), US$250 (Rest of World), €180 (Europe) £153 (UK). Prices are exclusive of tax. Asia-Pacific GST, Canadian GST and European VAT will be applied at the appropriate rates. For more information on current tax rates, please go to www.wileyonlinelibrary.com/tax-vat. The institutional price includes online access to the current and all online back files to January 1, 1997, where available. For other pricing options, including access information and terms and conditions, please visit www.wileyonlinelibrary.com/access.

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Production Editor: John Siever (ssm@wiley.com)

Electronic Access: This journal is available online at *Wiley Online Library*. Visit http://wileyonlinelibrary.com/ to search the articles and register for table of contents and email alerts.

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ISSN: 0036-6803 (Print)
ISSN: 1949-8594 (Online)
Printed in the US by The Sheridan Group.

IN THIS issue

Writing Papers in Math Class: A Tool for Encouraging Mathematical Exploration by Preservice Elementary Teachers

Christopher Danielson

This paper describes the author's attempt to design assignments that engage preservice elementary teachers in original mathematical thinking. In particular, the choice of integer operations as the focus of a structured writing assignment that takes students two weeks to complete is explained and justified. Exemplary student work is quoted.

The Effect of Nature of Science Metacognitive Prompts on Science Students' Content and Nature of Science Knowledge, Metacognition, and Self-Regulatory Efficacy

Erin Peters, Anastasia Kitsantas

The purpose of the present explanatory mixed-method design is to examine the effectiveness of a developmental intervention, Embedded Metacognitive Prompts based on Nature of Science (EMPNOS) to teach the nature of science using metacognitive prompts embedded in an inquiry unit. Eighty-three ($N = 83$) eighth-grade students from four classrooms were randomly assigned to an experimental and a comparison group. All participants were asked to respond to a number of tests (content and nature of science knowledge) and surveys (metacognition and self-regulatory efficacy). Participants were also interviewed. It was hypothesized that the experimental group would outperform the comparison group in all measures. Partial support for the hypotheses was found. Specifically, results showed significant gains in content knowledge and nature of science knowledge of the experimental group over the comparison group. Qualitative findings revealed that students in the comparison group reported scientific thinking in similar terms as the scientific method, while the experimental group reported that scientists were creative and had to explain events using evidence, which is more closely aligned to the aspects of the nature of science. EMPNOS may have implications as a useful classroom tool in guiding students to check their thinking for alignment to the nature of science.

Journey toward Teaching Mathematics through Problem Solving

Lynae E. Sakshaug, Kay A. Wohlhuter

Teaching mathematics through problem solving is a challenge for teachers who learned mathematics by doing exercises. How do teachers develop their own problem-solving abilities as well as their abilities to teach mathematics through problem solving? A group of teachers began the journey of learning to teach through problem solving while taking a Teaching Elementary School Mathematics graduate course. This course was designed to engage teachers in problem solving during class meetings and required them to do problem-solving action research in their classrooms. Although challenged by the course problem-solving work, teachers became more comfortable with the mathematics and recognized the importance of group work while problem solving. As they worked with their students, teachers were more confident in their students' abilities to be successful problem solvers. For some teachers, a strong problem-solving foundation was established. For others, the foundation was more tentative.

Writing Papers in Math Class: A Tool for Encouraging Mathematical Exploration by Preservice Elementary Teachers

Christopher Danielson
Normandale Community College

This paper describes the author's attempt to design assignments that engage preservice elementary teachers in original mathematical thinking. In particular, the choice of integer operations as the focus of a structured writing assignment that takes students two weeks to complete is explained and justified. Exemplary student work is quoted.

Identifying and teaching the mathematics necessary for teaching elementary school is a burgeoning field of research (e.g., Hill, Schilling, & Ball, 2004; Ma, 1999; Philipp et al., 2007). Informally, teachers of mathematics content courses for prospective elementary teachers frequently express frustration with motivating their students to take seriously the task of learning what appears to be *elementary* mathematics. Philipp (2008, p.2) has cited a commonly held belief among preservice elementary teachers that, "If I, as a college student, do *not* know something, then children would not be expected to know it, and if I *do* know something, I certainly don't need to learn it again." This belief is an obstacle to deep engagement with mathematics content courses on the part of prospective elementary teachers. There are several approaches to designing courses for this population, some of which address this belief and some of which do not.

One approach to content courses for prospective elementary teachers involves formalization of elementary mathematics. An example of this approach is the careful development of the standard algorithm for multi-digit whole number multiplication by means of the distributive property of multiplication over addition and the associative and commutative properties of addition and multiplication (e.g., Billstein, Libeskind, & Lott, 2003). This approach has an advantage of mathematical rigor and it develops knowledge that prospective elementary teachers tend to lack; explanations of *why* algorithms work. On its own, however, this approach does not address the belief cited by Philipp. That is, we do not expect elementary students to know formal justifications for the basic algorithms, so prospective elementary teachers may not understand why it would be important for teachers to know these justifications. This formalization approach, in short, may do little to motivate prospective elementary teachers to engage seriously in their mathematics content courses.

Another approach involves incorporating children's mathematical thinking into the content courses (Philipp et al., 2007). This approach demonstrates to prospective teachers that there is more to understanding, say, multiplication than knowing how to multiply. When students interview children or watch videos of children solving mathematics problems, they come to understand that there is more to elementary mathematics teaching than knowledge of arithmetic procedures; they come to understand that there is conceptual richness to the subject. In this approach, instructors motivate prospective elementary teachers to study mathematics by connecting to their existing deep interest in children.

As an example of how courses might differ under these two approaches, consider the study of the two conceptions of division: *sharing* and *measuring*.[1] In the first, formal approach, this distinction is unimportant. Division is seen as an abstract operation. Justification for the standard algorithm need not include a context for performing the division. Indeed, some texts for content courses for prospective elementary teachers (e.g., Billstein et al., 2003) do not include study of this distinction. Yet, while not formally important, the distinction between these two conceptions of division is conceptually very real. When asked to write a division word problem, most prospective elementary teachers write sharing problems and most find it difficult to think of a measuring problem. While this connection to context and to conceptual structures helps instructors to make headway on beliefs about the relevance of further study of elementary mathematics with prospective elementary teachers, we can use videos of students thinking about division to help seal the deal. The Cognitively Guided Instruction (CGI)

project (Carpenter, Fennema, Franke, & Levi, 1999) has two videos of the same student solving story problems leading to the division expression 21 ÷ 3. One of the problems is a measuring problem, which the girl solves swiftly by skip counting. The second problem is a sharing problem, which the girl solves with a great deal more difficulty. The task of understanding her thinking in each case is a valuable one for prospective elementary teachers, but the video can also be used simply to demonstrate that the distinction between the two types of division problems is real. It is the only meaningful difference between the two problems; the numbers are the same and each would reasonably be modeled with sets. In this way, the study of a mathematical topic is motivated by video of children's thinking.

The course described in this article draws on the second approach. The focus is on helping prospective elementary teachers develop a variety of ways of understanding topics in elementary mathematics and children's mathematical thinking is one tool the course uses. This article presents one instructor's attempt to use a unique form of assignment to motivate mathematical study by prospective elementary teachers: papers in math class. The idea is this: rich conceptual domains provide opportunities for learning mathematics through open, but structured exploration. In particular, I use addition and subtraction of integers to describe what is meant by a *rich conceptual domain*, and I describe how my course is structured to give students opportunities to explore this and other domains through exploration and original writing.

Addition and Subtraction of Integers as a Rich Conceptual Domain

By *rich conceptual domain*, I mean an area of mathematics that admits multiple parallel and equivalent ways of thinking. Counting is a complex skill but not a rich conceptual domain. Children need to learn the counting words and the order of these words. They need to learn to keep track of which objects have been counted and which have not. They need to maintain a one-to-one correspondence between number words and objects counted, etc. However, two children proficient at counting will count the same set of objects similarly.

By contrast, addition and subtraction of integers is a rich conceptual domain. Two children may have very different ways of thinking about finding the difference, –4 – (–3). One child may picture a chip model in which four red chips represent –4 and subtraction means *takeaway*. In this case, –4 – (–3) means to take three red chips from four, leaving one, so the answer is –1. The other child, on the other hand, may think of a number line on which –4 and –3 are locations. In this case, –4 – (–3) means, *how far (and in what direction) is –4 from –3?* Because each student may be perfectly proficient with his own way of thinking, yet have no conception of the other student's way of thinking, addition and subtraction of integers is a rich conceptual domain.

In fact, there are many ways of thinking about the addition and subtraction of integers. As an illustration, consider that the American journal *Mathematics Teaching in the Middle School,* published no fewer than five articles outlining various teaching methods for addition and subtraction of integers in 2007 alone.

Nurnberger-Haag (2007) offers a kinesthetic approach to the rules for adding and subtracting integers on a number line. In this model, the negative sign and the subtraction sign each mean *face the opposite way*. Thus, 3 – 4 is solved by starting at 0 on the number line, facing right, walking three spaces, then facing the opposite way (i.e., left) and walking four steps, ending at –1. A second problem, 3 – (–4), by contrast, is solved by starting at 0 on the number line, facing right and walking three spaces, but the walker then faces the opposite way twice—once for the subtraction, once for the negative sign—resulting in the walker facing right again. The walker walks four steps and ends at 7. In this approach, the location on the number line where the walker finishes walking is the answer to the computation.

Burkhart (2007) has designed a game that models integer addition and subtraction. Students draw cards from a specialized deck and move a marker right and left along a number line according to the sign and absolute value of the number on the card. The goal of the game is to land on a pre-determined number, called the *target*. Addition in the model corresponds to drawing a card from the deck. If Player A's piece is on 3 and she draws a –4, she moves four spaces to the left, ending at –1. Subtraction corresponds to discarding. On Player A's next turn, she could get rid of her –4 card and return to +3 on the number line. This model is similar to Nurnberger-Haag's model in that it involves motion on the number line. However, in Burkhart's model, addition and subtraction are based on getting and giving cards rather than on changing direction, and there is a distinction between the sign

and the operation that is absent in Nurnberger-Haag's model.

Kidd (2007) also uses the number line, but with a focus on subtraction. Kidd's concern is that the concept of absolute value is not well treated in many instances of integer instruction. Her argument is that students need to pay attention to the difference between "change in . . . " and "*amount of change* in . . . " (p. 518, emphasis added). If the temperature drops from 86° to 62°, the change is –24°, but the amount of change is 24° (the absolute value). She goes on to argue that there is an important difference between these two tasks:

1. Find the distance between 6 and 2 on the number line; and
2. Find the distance between 2 and 6 on the number line.

Kidd argues that only one of these (the latter) can be asked before negative numbers are introduced. Finally, Kidd recommends ideas for teaching that will help students to distinguish between |4–6| and |6–4|. While each of these expressions represents positive 2, Kidd interprets this positive 2 as representing a distance from zero. In the former expression, we start at 4, move 6 spaces left, and end at –2. In the latter expression, we start at 6, move 4 spaces left and end at +2. In each case, we end at a location that is two units from 0, but this location is distinct in each case.

Like Burkhart, Ponce (2007) uses a card game to introduce integers and the operations of addition and subtraction. Ponce's card game is more complex and it proceeds developmentally in *levels*. The simple first level has players compare two cards at a time with the black (i.e., positive) cards beating the red (i.e., negative) cards and the Joker (i.e., zero). In later levels, students record scores according to relationships between the colors and values of the cards drawn (e.g., if player A draws a red 2 and player B draws a red 4, then player A scores 6 red points) and they are given opportunities to change the color (i.e., sign) of a card or score. The game grows more complex as students advance through its levels. Number lines and colored dots or chips are added to the representations in later levels.

Gregg and Gregg (2007) use a debits-and-credits approach to introduce integers as composite units. They ask students to imagine a scenario in which children are paid in $1 chips when they complete chores and –$1 chips when they fail to do so. At the end of each month, the children's parents tally up the credits and debits and pay the children the corresponding allowance. A monthly allowance of $5 might be the result of earning seven $1 chips and two (–$1) chips, or it might be the result of earning 10 $1 chips and five (–$1) chips. By hiding debits, credits or total allowances, questions about addition and subtraction of integers arise.

Of course, these recent articles are not the only attempts that have been made at helping students to make sense of operations on integers—not even the only ones in this particular journal. Petrella (2001) talks with his students about positive thinking and negative thinking, while Reeves and Webb (2004) introduce integers using the context of helium balloons. All of these examples are in addition to some standard curricular approaches that involve: (1) rising and falling temperatures; and (2) colored chips. A teacher choosing a model for instruction has a complicated set of options. The reasons for making a choice can be varied as well; these might involve the teacher's own understanding of integers, time and material constraints, curricular expectations, and the teacher's prior experiences using one or more of the models in the classroom.

In most of these articles, the authors make pedagogical arguments in favor of the model in question. Nurnberger-Haag (2007) writes that her approach is "more effective, efficient and entertaining than other approaches" (p. 118). Burkhart (2007) describes students who are "deep in discussion" about "a meaningful activity" (p. 388). Ponce (2007) describes students who are "so engaged with this activity that few realize that they are learning about adding and subtracting integers" (p. 12). Gregg and Gregg (2007) have sought to "construct a scenario that makes it plausible to explain, for instance, why subtracting an integer is the same as adding its opposite" (p. 46).

Prospective elementary teachers tend to enjoy being introduced to some of these ways of thinking about operations on integers. They frequently report "getting it" for the first time because of one or another of the models. They talk about liking one model better than another and they begin to appreciate the conceptual richness of the topic. But *liking* and *appreciation*, while important pedagogical considerations and essential to the learning of mathematics (Sinclair, 2004), are not mathematical topics. Instead, these aspects of aesthetics may be used to motivate further engagement with purely mathematical topics.

We can imagine the series of articles cited previously as a professional conversation among colleagues. Their discussion focuses on pedagogical considerations that involve helping students to internalize, act out, understand, and deduce the correct rules for operating on integers. There is some disagreement in the conversation about whether the goal ought to be internalizing a set of given rules (as in the cases of Nurnberger-Haag [2007] and Ponce [2007]) or deducing correct rules as consequences of a reasonable and understandable situation (as in the cases of Burkhart [2007] and Gregg and Gregg [2007]). There is also disagreement about what exactly constitutes a reasonable and understandable situation. Reeves and Webb (2004) argue that the curricular two-color chip model, "because of a lack of an inherent problem-solving focus . . . usually do[es] not pique [students'] curiosity" (p. 476). For their part, Gregg and Gregg argue that "It is nearly impossible to avoid the contrived nature" of the various models and metaphors for working with integers and that, while the rules for integer computation follow from the definitions of integers and the operations, "the rules for calculating with helium balloons [the Reeves and Webb model] cannot be similarly deduced" (p. 47).

One goal of a program in teacher education ought to be to invite future teachers into this sort of conversation. Early in their programs, they are ill-equipped to engage meaningfully in the pedagogical side of this conversation. They can think about the aesthetics of the models from a personal perspective but judgments about what will be easy or difficult for their children to understand, or about which activities will foster deep discussion on the part of a variety of learners are subtle ones to make and require multiple experiences observing and working with schoolchildren. Instead, prospective elementary teachers may be invited to join the mathematical side of this conversation. These students come to their education programs with conceptions of integers and integer operations; we may ask them to expand on these conceptions by introducing new ones and by asking them to explore these new conceptions in structured ways.

Papers as a Structure for Exploration of a Rich Conceptual Domain

The first of two mathematics content courses I teach addresses the usual topics for such a course. The primary focus is on number and operation, including whole numbers, integers, fractions, decimals, and percents. Layered on top of these topics, however, is a small number of broadly applicable themes including: (1) representations of number; and (2) operation concepts.

Representations of Number

Most of the ways we represent numbers in mathematics can be put into three categories: sets, lines, and areas (see Figure 1).

Set Models. Set models are discrete; there is some smallest unit that does not get cut into smaller pieces. Additionally, set models represent numbers through quantity; we are concerned with how many things are in the set, and not with other attributes, such as size and shape. Small individual candies are an example of a set model; the number 6 is represented by six pieces of candy regardless of color, and we do not usually think about cutting small pieces of candy into fragments.

Linear Models. Linear models are continuous; each length can be cut into smaller lengths. We can represent numbers in two ways with a linear model: length and location. A long chocolate bar is an example of a linear model. We have experience cutting a long candy bar into several pieces; we usually only cut across the bar and the lengths of the resulting pieces matter very much in naming the pieces. Long chocolate bars de-emphasize the location nature of numbers in a linear model. Other linear models, such as roadways, bring it to light.

Area Models. Area models are also continuous. With an area model we do not ask *how many?* or *how long?* but *how big?* We cut areas into smaller pieces, rearrange them and understand that these processes do not change the value in question. A wide, flat chocolate bar is an example of an area model; it is cut on two dimensions, we can imagine cutting it into smaller and smaller pieces and 1/3 of the bar can take several different forms that may not be obviously equal at first glance.

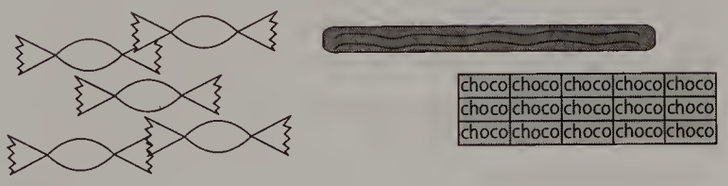

Figure 1. Candy: Individual pieces of candy are a set model for number; long chocolate bars are a linear model; wide chocolate bars are an area model.

Modifications to the Model Types

These are descriptions of the models in their purest forms, but we sometimes add a rule or two to one of these forms in order to consider some new idea. For instance, the two-color chip model familiar to most middle school math teachers and referenced by several of the participants in our imaginary conversation is a set model with an added structure; color matters. Usually, we use black chips to represent positive numbers and red chips to represent negative numbers, but we are counting the chips without regard to size, location, or shape and we do not usually think about cutting the chips into smaller pieces, so the model is discrete. In this way, set models, area models, and linear models are broad categories rather than meticulously defined ones.

Not all models for representing numbers fit into these categories. For instance, money as a model for thinking about decimals is outside of these categories: each coin and bill have different values, so we do not simply count the objects in our pockets to determine how much money we have. Length and size are similarly nonsensical for interpreting values of money. Nonetheless, the three broad categories described here help to make precise some mathematical commonalities and differences among the proposed models for teaching integers.

Operation Concepts

As discussed in the introduction to this paper, the two conceptions of division are fundamental to the course being described here because, while not important from a formal mathematical perspective, they are in fact very real distinctions in how people think about the operation, and this is important knowledge for teaching. Similarly, the addition and subtraction problem types documented in the Cognitively Guided Instruction (CGI) research (Carpenter et al., 1999) are fundamental ideas in my course.

A major contribution of the CGI research is that children's thinking about the basic operations is more complex and more subtle than a simple correspondence of key words with operations. The CGI research took place among young (second grade) students and involved problems that were most easily directly modeled with set models; one apple or one marble counts as a unit, regardless of size or other characteristics. When we consider addition and subtraction models in a linear context, the CGI categories do not stand out as starkly,[2] but they still provide a basis for seeing similarities and differences in instructional approaches.

Writing Papers in Math Class

Papers in my mathematics content course for prospective elementary teachers introduce a mathematical idea that my students can see as directly relevant to their future teaching and ask them to analyze this idea in terms of the themes of the course. The term *paper* is used to signal to students that more is required of them than would be typical of a homework assignment in math class. As an example, most of my students have not encountered the lattice algorithm[3] for whole number multiplication. Those who have seen the algorithm before have seen it in the context of working with children, as the algorithm is taught in an American mathematics curriculum (University of Chicago School Mathematics Project, 1997) that has seen wide adoption in our area. My students write a paper about the lattice algorithm. This paper has three components: (1) learn to perform the algorithm; (2) work a variety of problems using the algorithm; and (3) analyze the algorithm using the themes of the course.

The first component is straightforward and students tend not to have difficulty learning to perform the algorithm. Because they are not instructed which problems to work, my students are challenged by the second component, the requirement that they choose the variety of problems. With varying degrees of success, my students have used the algorithm to work on:

1. single digit problems;
2. multi-digit problems;
3. problems involving decimals;
4. problems involving negative integers;
5. problems involving fractions;
6. addition problems; and
7. variable expressions.

I frequently learn something new from my students' work on the third component. Initially, I expected there to be no connection between the model types and the lattice algorithm. I expected my students to tell me that the algorithm is an abstraction without meaningful connections to these more concrete models. Instead, several have noticed that if we subdivide an area model according to place value, then the smaller rectangles are arranged in the same way as the cells of the lattice (Figure 2). This arrangement allows us to see two abstractions (or maybe it is just one abstraction, represented two ways): (1) the lattice grid is non-proportional in contrast to the area model—the

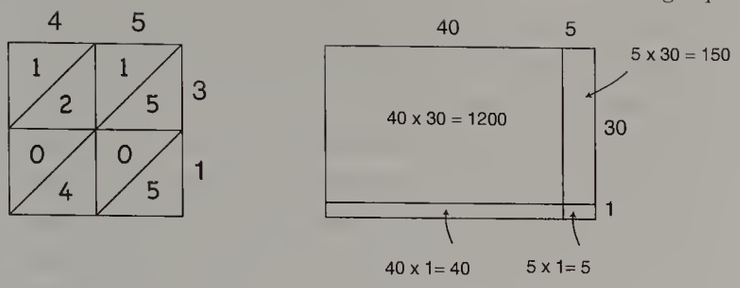

Figure 2. Lattice Area: The arrangement of the cells in the lattice on the left matches the subdivisions of the area model on the right. The lattice is non-proportional and place value is implicit.

cells are all the same size regardless of the numbers they represent; and (2) each cell of the lattice represents a different unit—one cell represents ones, others represent tens, etc., but this structure keeps us from paying attention to place value.

In this way, papers in my math courses are tools for tapping into my students' interest in teaching children and getting them to think mathematically.

An Example of a Paper

The Assignment

Now I present an example of a paper that uses the rich conceptual domain of integer subtraction to invite students into the professional conversation I outlined earlier. I also include excerpts from an actual student paper to demonstrate the mathematical thinking I aim for my students to do through this and other papers.

Investigations in Number, Data and Space is an American elementary curriculum (ages 5–11) that emphasizes student mathematical reasoning and sense-making. Many of the ideas in the curriculum are grounded in students' lived experiences. A second grade unit (for 7-year-old students) titled *Up and Down the Number Line* (Weinberg, Tierney, & Cory, 1998) introduces negative numbers in the context of a building with an elevator that runs to floors above and below ground. Zero is the ground floor; above that are floors numbered 1, 2, 3, etc., and below ground are floors labeled B1, B2, B3, etc., where B1 is one floor below ground. Students imagine and represent elevator rides that go up and down, and between basement and aboveground floors.

For the paper, I present this basic context to students and then impose a subtraction structure on it: *ending floor – starting floor = net change*. In this interpretation, 4 – (–5) means that we started on the fifth floor below ground and rode to the fourth floor above ground. To do so, we rode up nine floors, so 4 – (–5) = 9. The paper asks students to: (1) use the model to interpret subtraction problems; and (2) analyze the model using the themes of the course.

A Student's Paper

At a basic level, a goal for the paper is to develop a habit of mind that I consider essential for teaching mathematics: taking the time to understand a new perspective on a familiar topic. By the time my students write this paper, they have experience with a variety of models for subtracting integers. The elevator setup is deliberately designed to force a different interpretation of subtraction. For many of my students, this is sufficient intellectual challenge. At a more sophisticated level, I hope also to push students to consider new perspectives on the themes of the course, and I hope that they will think seriously about the examples they choose in exploring the model.

In this section, I present some excerpts from the paper of a recent student, Elise. I chose her paper to excerpt because she writes well and because she shows insights that seem to have developed from her engagement with the paper.

Elise began her paper with a series of word problems.

> *Joe is a janitor who works in the tallest skyscraper in the world. There are floors that go not only above ground, but below ground. The scientists who work in the building are very messy and their experiments spill all the time. It is Joe's job to help them clean up their messes so he has to go up and down the elevator a lot during the day.*
>
> *1. Joe goes into work on the ground floor (0) and goes up to the fifth floor to his supply room. How many floors does Joe travel?*
> *2. From here (the 5th floor), Joe must go to the 12th floor where a messy scientist spilled his ultra-sticky goo all over the carpet and asked Joe to help in cleaning it up. How many floors did Joe travel now, from the 5th floor to the 12th floor?*
> *3. After cleaning up the ultra-sticky goo on the 12th floor, Joe goes back to his supply room on the 5th floor to take his lunch break. How many floors does Joe travel from the 12th floor to the 5th floor?*

In Elise's remaining problems, Joe travels both up and down underground and eventually returns to his supply room at the end of the day.

When designing the word problems, I wanted to use a variety of problems to help the students explore as many different types of subtraction problems as possible. The first problem uses the number zero for the students to understand what zero does to other numbers (i.e., nothing when dealing with subtraction; 5 – 0 = 5). In the second problem, I wanted to use two positive numbers to start off with something they are more familiar with (12 – 5 = 7). The third problem, I chose to use the same numbers, but reverse the order they appear in the word problem so students would recognize that the answer is still the same (seven floors), but the answer changes to a negative form (5 – 12 = –7).

Elise makes an observation here that is similar to the one cited by Kidd (2007) earlier; there is a distinction between the number of floors traveled (absolute value) and the directed length of the elevator ride. She is reflective about this difference later in the paper.

When I first started solving the problems, I had just taken the bigger number minus the smaller number to get the net change. This made it so that I always had the absolute value of the . . . answer. The absolute value is the correct answer for the word problems (how many floors did Joe travel?) but not the correct answer for the subtraction problem, which is what the student is trying to learn.

This paragraph captures my motivation for having students write papers in math class. Elise has had insights about absolute value and about the relationship between order of subtraction and the sign of the answer. However, these insights have been motivated by thinking about how children might interact with the model, rather than by their purely mathematical properties. Elementary curriculum has brought imagined student thinking into Elise's experience in the content course; this imagined student thinking provides a place for her (and my other students) to explore mathematical ideas.

Elise also notices something about the relationship between the elevator model and the walking on a number line model that we explored in class.

Before taking on this task, I believed the skyscraper model to be the same as the number line when dealing with subtraction. After working out the problems, I soon found this to be false. I noticed that when dealing with the number line, children don't necessarily need to understand subtraction before walking on the number line. The number line has a set of rules which help them to find the answer (face left/right, walk forwards/backwards). The elevator, however, doesn't have these rules, so when negative numbers are added into the word problem, a child must know that 5 – (–7) = 5 + 7 in order to understand how the elevator relates to the equation being set up.

Elise's basic assertion that the skyscraper model is different from walking on the number line demonstrates that she has met the goal of understanding a familiar topic from a new perspective. To many students, the two models appear identical because they each deal with linear motion. Even students who successfully interpret problems in the form *end – start = net change* sometimes fail to notice the conceptual difference between this form and the form *start ± change = end*. Her secondary assertion, that *a child must know that 5 – (–7) = 5 + 7 in order to understand how the elevator relates to the equation being set up*, leads to productive discussion back in my classroom. I can pose the question *does a student need to know that subtracting a negative is equivalent to adding a positive in order to solve these problems, or can these problems lead students to notice this?*

Conclusion

Papers in math class have proven to be productive tools for motivating my preservice elementary teachers to study elementary mathematics from a fresh perspective. By situating open and analytical tasks in contexts that relate directly to the teaching of elementary mathematics. I help my students to see my mathematics content course as relevant to their future work. As a result, they are more willing to think deeply about topics they first learned when they themselves were children.

Other topics I have successfully used for paper writing in this course include the following:

1. Analysis of the common denominator fraction division algorithm, which I present as an alternate strategy developed by a hypothetical student.
2. Solving a series of percent problems designed to challenge students' ability to identify and to represent the whole.

Finally, in conjunction with a novel approach to teaching place value (Hopkins & Cady, 2007) that I have recently incorporated into the course, I am developing a paper that has students rework an elementary school place value lesson from a published curriculum into an alternate number system and write about their thinking process in doing so.

However, the sort of writing I have described here does not happen simply because it is assigned. These papers are embedded in a course that provides frameworks for analysis of mathematical ideas (such as model types and the CGI problem types), and that provides opportunities for doing this kind of analysis during class sessions. In short, paper writing in math class is but one part of a course that is structured to make future elementary teachers think critically about mathematics they thought they already knew.

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Author's Notes

[1] These are also called *partitive* and *quotative* division, respectively.

[2] For instance, *counting on*, a hallmark strategy of *Join* problems, is problematic in fraction addition; there is no "next fraction" to count.

[3] See e.g., Nugent (2007) and Danielson (2008).

The Effect of Nature of Science Metacognitive Prompts on Science Students' Content and Nature of Science Knowledge, Metacognition, and Self-Regulatory Efficacy

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The purpose of the present explanatory mixed-method design is to examine the effectiveness of a developmental intervention, Embedded Metacognitive Prompts based on Nature of Science (EMPNOS) to teach the nature of science using metacognitive prompts embedded in an inquiry unit. Eighty-three (N = 83) eighth-grade students from four classrooms were randomly assigned to an experimental and a comparison group. All participants were asked to respond to a number of tests (content and nature of science knowledge) and surveys (metacognition and self-regulatory efficacy). Participants were also interviewed. It was hypothesized that the experimental group would outperform the comparison group in all measures. Partial support for the hypotheses was found. Specifically, results showed significant gains in content knowledge and nature of science knowledge of the experimental group over the comparison group. Qualitative findings revealed that students in the comparison group reported scientific thinking in similar terms as the scientific method, while the experimental group reported that scientists were creative and had to explain events using evidence, which is more closely aligned to the aspects of the nature of science. EMPNOS may have implications as a useful classroom tool in guiding students to check their thinking for alignment to the nature of science.

Many teachers have only a surface understanding of how science operates as a discipline and have difficulty creating lessons that present science as a disciple rather than a collection of facts (Abd-El-Khalick & Akerson, 2004; Akerson, Abd-El-Khalick & Lederman, 2000; Bianchini & Colburn, 2000; Chin & Brown, 2000). If students are offered inadequate versions of how science operates as a discipline, students will leave the classroom understanding that there is a collection of facts that are scientific, but not much else (American Association for the Advancement of Science, 1993; Chin & Brown; Crawford, 2005; Crawford, Kelly, & Brown, 2000; Gijlers & de Jong, 2005; Hogan, 1999a; National Research Council, 1996; Schwartz, Lederman, & Crawford, 2004; Schwartz & Lederman, 2002). Students who have a deep understanding of the nature of science may be more able to make decisions for processes in their inquiry leading to content that is more scientifically valid (Akerson & Abd-El-Khalick, 2003; Crawford, 2005; Duschl, 1990). Given the importance of the nature of science, only a few instructional interventions have been developed to teach it effectively (Abd-El-Khalick, Bell, & Lederman, 1998; Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson; Khishfe & Abd-El-Khalick, 2002) and, to our knowledge, no attempt has been made to incorporate self-regulatory processes in these interventions. Self-regulation refers to the degree to which students are metacognitively, motivationally, and behaviorally active participants in their own learning process (Zimmerman, 1989). Use of self-regulatory processes has been significantly correlated with student academic outcomes (Kitsantas, 2002; Zimmerman, 1998) and motivational beliefs such as self-efficacy and intrinsic interest in a task (Zimmerman, 2000). The purpose of this study is to investigate the effectiveness of an intervention (Embedded Metacognitive Prompts based on Nature of Science; EMPNOS), which attempts to the impact of metacognitive prompts through self-regulatory training on student content knowledge, nature of science knowledge, metacognition, and self-regulatory efficacy (students' perceptions of efficacy regarding their capability to self-regulate their learning).

Nature of Scientific Knowledge

In recent years, researchers have converged on aspects of the nature of science and, more recently, there has been an agreement on the elements of the nature of science (Abd-El-Khalick et al., 1998; McComas, Almazroa, & Clough, 1998). The literature

converges on seven aspects of the nature of science that defines science as a discipline: (1) scientific knowledge is durable, yet tentative; (2) empirical evidence is used to support ideas in science; (3) social and historical factors play a role in the construction of scientific knowledge; (4) laws and theories play a central role in developing scientific knowledge, yet they have different functions; (5) accurate record keeping, peer review and replication of experiments help to validate scientific ideas; (6) science is a creative endeavor; and (7) science and technology are not the same, but they impact each other (McComas, 2005). Evidence of these aspects of the nature of science as the foundation for how science operates as a discipline can be found in science education research journals, books about the philosophy and epistemology of science, and practitioner handbooks.

Although it is intuitive to think that just by conducting inquiry that students will understand how scientists operate, there is a body of research that demonstrates explicit instruction in the nature of science has been found to be more effective. Khishfe and Abd-El-Khalick (2002) have shown significant gains in student nature of science knowledge through explicit and reflective means. A succession of studies with preservice elementary teachers has shown evidence supporting the effectiveness of an explicit reflective approach to teaching the nature of science (Abd-El-Khalick, 2005; Abd-El-Khalick et al., 1998; Abd-El-Khalick & Akerson, 2004; Khishfe & Abd-El-Khalick, 2002). The core design idea of the intervention in this study is the explicit and developmental method used to connect the nature of science to student construction of knowledge.

Teaching the nature of science out of the context of scientific knowledge and inquiry does not give students access to the important connection between scientific knowledge and knowledge about science (Duschl, 1990). Often teachers with an elaborate understanding of the nature of science and who are motivated to teach their students about the nature of science have unproductive outcomes when trying to explicitly identify aspect of the nature of science during inquiry activities (Akerson et al., 2000). Mellado (1997) has shown that preservice teachers have no correspondence between teacher conceptions of the nature of science and classroom practice, and Tobin and McRobbie (1997) have demonstrated that even when both teachers and students believed science to be an evolving discipline, the representation of knowledge in the classroom was static. A user-friendly and theory-based intervention is needed to help teachers have a broader impact in nature of science instruction.

Prompting Active Metacognition through Self-Regulatory Training

Cognitive change can be invoked through deep processes such as metacognition (Flavell, 1987). Metacognition is the ability to think about and evaluate your own thinking processes (Brown, 1987) and provides the mechanisms for students to regulate their cognition and learning (Zimmerman, 1998). There is some evidence that attainment of high levels of academic achievement requires a self-regulatory dimension of competence in addition to basic talent and high-quality instruction (Zimmerman & Kitsantas, 2005). In order to accomplish the goal of learning about the nature of science and science content, students can perform inquiry activities, think about why they are conducting certain processes and, in turn, evaluate their thinking in terms of the agreed upon processes of the scientific community (Dawson, 2000). The use of metacognition has been shown to improve content knowledge (Magntorn & Hellden, 2005) and solution quality (Wetzstein & Hacker, 2004). Most research in the field of metacognition and science has been focused on listening to group conversations or asking students to talk aloud about their thinking (Blank, 2000). These passive activities do not give the students the modeling they may need to understand the aspects of the nature of science, as students are not typically exposed to ways of knowing in science (Hogan, 1999b). Metacognitive prompts built from the identified aspects of the nature of science (McComas et al., 1998) may give teachers a vehicle to scaffold scientific thinking to students who are underexposed to this type of thinking.

But how do students develop self-regulatory skills? Research shows that self-regulation of skills can be proactively developed through four levels: observation, emulation, self-control, and self-regulation (Zimmerman, 2000). The sequence of the four developmental phases has been empirically tested, and the results support the sequential advantage of each phase (Zimmerman & Kitsantas, 2005). The observation phase occurs when a student notes the process of a model throughout a specific task whereas the emulation phase occurs when a student attempts to try to be like the model and receives support. The self-control phase occurs when the student independently

uses the strategy in similar contexts, and the self-regulation phase occurs when the student can adapt the use of the strategy across changing conditions (Zimmerman). This model has been used successfully in training students to achieve various learning tasks such as writing (Zimmerman & Kitsantas, 2002) and motoric skill proficiency (Kitsantas & Zimmerman, 2006) and sustain their self-efficacy to continue pursuing these tasks (Zimmerman & Kitsantas). One possible reason that teachers as well as students have difficulty understanding the nature of science is their lack of exposure to the same inherent ways of knowing as a scientist (Hogan, 2000). Self-regulated learning strategies such as metacognitive prompts could provide a framework that can scaffold naïve views of the nature of science to more developed views of the nature of science. To our knowledge, the effectiveness of this approach has not been examined with a science task.

This study attempts to draw from the understandings found in the literature regarding the nature of science and self-regulatory processes such as metacognition, and implements the seven identified aspects of the nature of science (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; McComas, 2005) in learning modules to guide student thinking processes to become more scientific. It has been shown that student understanding cannot occur passively (Akerson, Flick, & Lederman, 2000; Ryer, Leach, & Driver, 1999), so the proposed intervention is suited to evoke student cognitive change regarding conceptions of the nature of science. Students who use explicit metacognitive strategies can evaluate their thinking to determine if it aligns with the rigorous requirements of science. It is hypothesized that there will be positive correlations among content knowledge, knowledge about the nature of science, metacognition and self-regulatory efficacy. It was also hypothesized that students exposed to EMPNOS would report a higher level of content and nature of science knowledge, metacognition and self-regulatory efficacy.

Methods

Design of the Study

This explanatory mixed method study (Creswell & Plano Clark, 2007) was designed to show differences in content knowledge, knowledge of the nature of science, metacognition, and self-regulatory efficacy within and between the comparison and experimental group. The purpose of an explanatory mixed method design is to utilize the quantitative portion of the study to yield useful information about outcomes, and then conduct additional collection of qualitative data to address processes of how the experiment worked. For the quantitative portion of the study, students from four eighth-grade classes were given measures of metacognitive orientation of the classroom, metacognition in science, self-regulatory efficacy, nature of science, and content before the intervention began. Classes were then chosen randomly to be in the comparison group or the experimental group. The inquiry units without the embedded metacognitive prompts were given to the comparison group and the inquiry units with the EMPNOS were given to the experimental group. Students studied the phenomena using the four modules of the intervention with the guidance of the teacher/researcher. Student groups of three or four used the module packets to investigate the learning goals in electricity and magnetism. The teacher/researcher acted as a facilitator in their learning process and wrote reflective researcher memos throughout the intervention. Fidelity among the four classes was maintained through the observation, and comments of a colleague who did not interact with the students, a script for the opening activity and the closing activity that was implemented for each inquiry unit, and a checklist form for the teacher to ensure implementation accuracy. After the second module was complete, all students took the self-regulatory measure in order to measure a midpoint, which could fluctuate while the intervention is in progress. After all four modules were complete, students took the measures as a post-test. A qualitative portion of the study used student focus group interviews, think aloud protocols, and work products to describe processes the different groups used to learn the nature of science.

A Description of the Intervention

EMPNOS consists of checklists and questions organized into four developmental phases strategically placed into lesson plans. Each set of metacognitive prompts represent ideas from one of the seven aspects of the nature of science. Module one focused on empirical data, module two focused on laws and theories, module three focused on peer review and data collection, and module four focused on creativity. In order to address the issue of added time on-task for the experimental group, since they spent time on the checklists and the questions in the prompts, the comparison group was given additional physical science content questions in their inquiry units. The time it

took for students to answer content questions in the comparison group matched the time it took to address the prompts in the experimental group's intervention.

Because the prompts are developmental, each nature of science aspect had four phases of prompts based on Zimmerman's (2000) model of self-regulation: observation, emulation, self-control, and self-regulation. The observation phase prompts give examples of how a scientist would address the aspect of the nature of science in the module and the rationale behind it. The observation phase prompts were placed after the first investigation of new phenomena in the module in order to give students an example of how a scientist would answer the question. Students were expected to read and understand the model from the observation phase while in their lab groups of three or four members. The emulation phase gives a checklist to the student about the aspects of nature of science that should be considered for the task. The emulation phase was placed after the second investigation of the new phenomena so that students could perform a similar task as the model in the observation phase given the support of the checklist. Students were expected to emulate the model task and check their work using the checklist while in their groups, and were expected to discuss their activities with their lab group. The self-control phase gives students a short checklist of major aspects of the nature of science as well as some simple questions about "thinking about their thinking." The self-control phase was placed after the investigations in the phenomena so that students could reflect on their choices and rationale. Students were expected to answer the self-control phase while in the lab group to discuss answers with peers. The self-regulation phase gives students more advanced questions that ask students to check to see if their thinking is aligned with the nature of science aspect. The self-regulation phase was placed at the end of the module so that students could reflect on the combination of activities in the entire module. The self-regulation phase questions were taken home to complete individually as homework. The groups checked each others' answers the next day in class and the teacher discussed their answers as a warmup to the class activities. Table 1 lists the metacognitive prompts for the first of the four modules, which focused on the empirical aspect of the nature of science.

Both experimental and comparison groups were studying the science content through inquiry units that require students to make observations and inferences about phenomena (National Research Council, 1996). However, the experimental unit had the metacognitive prompts embedded into the unit. The modules cover the content of electricity and magnetism at an eighth grade level. Each module had three distinct tasks, eliciting prior knowledge individually and reporting knowledge about the particular content as a class, conducting two or three investigations on new phenomena, and summarizing the "big ideas" in the module using evidence found in the investigations.

The comparison group learned about the nature of science implicitly because the students needed to observe phenomena, describe their observations, explain their reasoning, and summarize the overarching ideas in the module. The experimental group was asked to complete the same tasks, but they were given the metacognitive prompts that explicitly required students to check their work for alignment to the chosen aspect of the nature of science. The comparison group was not excluded from learning about the nature of science, but the intervention was designed so they could learn implicitly in the following ways: basing summaries on the evidence (empirical), making the cognitive leap from observations to conclusions (creativity), discussion of ideas in groups and compared ideas across groups (social), use of tools to measure and collect data (technology), changing their ideas based on other students' evidence (tentativeness), and developing their own data tables and methods of organization (habits of mind). The modules were designed for all students to be exposed implicitly to the nature of science through the processes, and the experimental group was also exposed to the nature of science explicitly through the metacognitive prompts.

Quantitative Analysis: Study I

Participants. Eighty-three eighth-grade science students from an urban middle school in the mid-Atlantic region of the United States participated in the study. The middle school serves 928 students, grades six through eight. Seventeen percent of students from this school receive free or reduced price for lunches. The sample population consisted of 8% black students, 11% Hispanic students, and 81% white students.

Four classes with approximately 23 students in each class were selected for this study. When teachers at the school organized the classes at the beginning of the year, they ask seventh grade teachers to rate students as high, middle, or low achievers. Eighth-grade teachers place equal numbers of high, middle, and low

Table 1
Example Metacognitive Prompts

Topic: Permanent Magnets	
Nature of Science Aspect: Empirical evidence is used to support ideas in science	
Phase 1 – Observation	*Example: I would want to explain things in great detail, so other people could understand my exploration. I would measure how far apart the magnets were when the interaction happened. Magnet #1 started to move away from Magnet #2 when I brought Magnet #2 closer. This started to happen when the magnets were 1 cm away from each other, and continued as they got even closer.*
Phase 2 – Emulation	*1. My observations describe what I see, hear or feel.* *2. My observations are made up of measurements that other people can agree upon. For example, instead of saying "It is big", I say "The blue car is 20 cm long"* *3. My observations are clear to other people who are not performing this lab.* *4. My observations come only from my five senses, and are not inferences.* *5. My observations can be used later to make conclusions.* *6. My observations are not judgments about what I see, hear or feel.*
Phase 3 – Self-control	1. Are your observations clear to other people? Explain why you think that. 2. Check your explanations against your observations. Do they make sense together? Explain with one example. *3. My observations are clear to other people who are not performing this lab.* *4. My observations come only from my five senses, and are not inferences.* *5. My observations can be used later to make conclusions.*
Phase 4 – Self-regulation	• Can other people understand your observation out of context? How do you know that? • Is your observation free of any judgment? Explain. • Are your observations relevant to the purpose of the investigation? Explain how they are. • What big ideas (theory) did you use to make sense of your observations? • What generalization did you develop because of your observations? • How do your observations support this generalization? • What do scientists understand about your generalization? • Has your thinking about the observations become more like an expert?

students, and they make every attempt to have the class composed of 50% girls and 50% boys. The first author was also the science teacher for all four classes, and had established a relationship with the classes for one school year. The intervention was given at the end of the year, allowing the students to have experienced a spectrum of inquiry activities over the year ranging from teacher-led guided inquiry to student-generated problem-based learning scenarios. Therefore, the inquiry portion of the intervention that was given to both groups was not a new learning experience.

Measures

Metacognitive Orientation Scale (MOLES-S). The MOLES-S (Thomas, 2002) is designed with a social constructivist view in mind and considers that knowledge is not constructed in a vacuum, but is developed through interactions with the learning environment. Eight aspects of metacognition which were supported by the research literature were measured on the MOLES-S: (1) metacognitive demands; (2) teacher modeling and explanation; (3) student–student discourse; (4) student–teacher discourse; (5) student voice; (6) distributed control; (7) teacher encouragement and support; and (8) emotional support. The MOLES-S is a 67-item instrument that includes the eight aforementioned dimensions based on a Likert-scale. During validation, the initial instrument was administered to 1,026 students within the 14–17-year-old age group. The MOLES-S reported an alpha reliability ranging from .72 to .87 for each of the seven scales, and all of the scales showed to be statistically significant. The discriminant validity ranged from .34 to .49 for each scale.

Metacognition of Nature of Science Scale (MONOS). The MONOS (Peters, 2009) 16-item survey was designed to test five different student metacognition processes in science: observation, data collection, measurement, and making conclusions. Students were asked to choose a number between 1 and 5 to show whether they agreed with the statement (5) or disagreed with the statement (1). Field tests of the survey were conducted with three high-achieving, three average-achieving and three low-achieving readers from the eighth grade. Feedback regarding comprehension and meaning of the questions provided during the field test interviews after the survey guided the revisions of the instrument. Changes in the statements were made based on the interviews of the students after the draft survey was administered. The students involved in the field test did not take the survey, since they had prior knowledge of the intention of the survey. Table 2 shows examples of items from the *MONOS.* Reliability as measured by Cronbach alpha for the entire instrument is .89. Factor analyses showed that is primarily a single factor explaining approximately 54% of the variance.

Table 2
Sample Items from Unpublished Measures

Measure	Sample Questions
Test of Electricity and Magnetism Knowledge	Why are some materials magnetic while others are not?
	Why do certain materials hold static electric charges more effectively?
	Draw a picture of a complete electric circuit with one cell, one bulb and a switch.
	Name two ways to make an electromagnet stronger.
Metacognition of the Nature of Science	When I complete a lab in science, I think about how the lab could be improved.
	When I measure objects in science, I think about possible errors I could make when making measurements.
	When I record data in science, I can understand what I did, even weeks after I gathered the data.

Self-Efficacy for Learning Form (SELF). The SELF scale (Zimmerman & Kitsantas, 2007) is a 19-item survey designed to access student self-efficacy for self-regulated learning. The items are designed to capture students' certainty of coping with various academic challenges (e.g., note taking, test taking, and general studying). The students responded using a scale that ranged from 0 to 100 points in 10-unit instruments. Written descriptions of this scale included: 0 (definitely cannot do it), 30 (probably cannot do it), 50 (maybe), 70 (probably can), and 100 (definitely can do it). Higher

scores on this scale represent a more positive self-efficacy for self-regulated learning. This scale has been validated with high school students and was highly correlated to teacher reports on students. The inter-item reliability of this scale is $\alpha = .97$.

Test of Electricity-Magnetism Knowledge (TEMK). The science content taught during the intervention includes magnetism, static electricity, current electricity, and electromagnetism. The TEMK (Peters, 2009) assesses each students' attainment of content goals at an eighth grade level: (1) behavior of static electrical charges; (2) behavior of electrical current; (3) behavior and internal mechanisms of magnets; and (4) behavior of electromagnetic interactions. The questions on this test are open-ended and assess each of the content goals using visual, logical, and analytical forms of communication. Each question on the TEMK was ranked using a 0–3 scale: 0 representing no answer, 1 representing novice knowledge, 2 representing emerging knowledge, and 3 representing proficient knowledge, the same system used on the National Assessment of Educational Progress (National Center for Educational Statistics, 2007). A panel of award-winning teachers reviewed the TEMK to verify that the questions and scoring rubrics would elicit student knowledge of the learning goals in the modules. Inter-rater reliability was found to be Cronbach $\kappa = .92$. The Cronbach alpha reliability on the TEMK scoring was measured at .82. Table 2 includes sample items from this content measure.

The Views of the Nature of Science – Form B (VNOS–B). The VNOS-B (Lederman et al., 2002) assesses student understanding of science as a way of knowing and consists of seven open-ended questions corresponding to the seven identified aspects of the nature of science. Lederman et al. (2002) argue that due to the nature of information being gathered on the VNOS-B, the structure of the assessment should be free-response. Each question on the VNOS-B was ranked using a 0–3 scale: 0 representing no answer, 1 representing novice knowledge, 2 representing emerging knowledge, and 3 representing proficient knowledge. Inter-rater reliability on this measure was 94%. In addition to the scoring rubric, questions from the VNOS-B were included in the focus group interviews, as suggested in the literature (Lederman et al., 2002).

Quantitative Results

Descriptive statistics were calculated and pair *t*-tests, independent *t*-tests, and repeated measures were performed to identify differences in metacognition, self-efficacy, content knowledge, and nature of science knowledge between and within the experimental and comparison groups (see Table 3).

As hypothesized, positive correlations among all five variables emerged. Specifically, high correlations

Table 3

Means and Standard Deviations between the Comparison and the Experimental Groups for All Variables

Variables	Comparison Group						Experimental Group					
	Pre		Post		Mid		Pre		Post		Mid	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Test of Electricity and Magnetism Knowledge	.56	.36	1.54	.47			.60	.41	1.89	.40		
Metacognitive Orientation Scale – Science	3.64	.58	3.93	.56			3.65	.41	3.83	.53		
Metacognition of Nature of Science Scale	3.80	.58	3.83	.60			3.60	.51	3.83	.49		
Views of the Nature of Science Version B	1.01	.48	1.14	.56			1.04	.32	1.45	.37		
Self-Efficacy of Learning Scale	7.00	1.37	7.13	1.37	7.42	1.36	7.20	1.20	7.11	1.53	7.68	1.84

Table 4
Correlations Among the Measures of Self-efficacy, Metacognition, Content Knowledge, and Nature of Science Knowledge

Variables	1	2	3	4	5
1. Test of Electricity and Magnetism Knowledge (TEMK)	1.00				
2. Metacognitive Orientation Scale – Science (MOLES-S)	.07	1.00			
3. Metacognition of Nature of Science Scale (MONOS)	.41**	.55**	1.00		
4. Views of the Nature of Science Version B (VNOS-B)	.52**	.01	.28*	1.00	
5. Self-Efficacy of Learning Scale (SELF)	.29*	.46**	.63**	.27*	1.00

Note. ** Correlation is significant at the .01 level (two-tailed).
* Correlation is significant at the .05 level (one-tailed).

were found between SELF and MONOS, $r = .63$, $p < .001$ and nature of science knowledge (VNOS-B) and content knowledge (TEMK) $r = .52$, $p < .001$. Significant moderate correlations were found between MONOS and MOLES-S, $r = .55$, $p < .001$; TEMK and MONOS, $r(65) = .41$, $p = .001$; MONOS and VNOS-B, $r(70) = .28$, $p = .02$; SELF and TEMK, $r(64) = .29$, $p = .02$; SELF and VNOS-B, $r(70) = .27$, $p = .03$; and SELF and MOLES-S, $r(71) = .46$, $p < .001$. Table 4 presents correlations for study variables.

Independent *t*-tests performed to test for pre-test differences for all variables between the experimental and comparison groups revealed no significant differences for any of the measures, all $p > .05$. These findings align with the policy of the school in which the study was conducted because in science classes, students are placed into heterogeneous groups according to performance in the prior grade level. Given the findings of these analyses, independent *t*-tests were performed to test the hypotheses that the experimental group will outperform the comparison group on all five post-measures. Significant differences emerged between the experimental group and the comparison group in content knowledge, $t(1, 67) = 2.66$, $p < .01$ and nature of science knowledge, $t(1, 70) = 3.02$, $p < .01$. The experimental group demonstrated a greater gain in content knowledge ($M = 1.89$) and knowledge about the nature of science ($M = 1.45$) than the comparison group ($M = 1.54$) and ($M = 1.14$) respectively. Neither metacognitive orientation of the classroom, $t(1,80) = 0.76$, $p = .45$, nor metacognition of the nature of science, $t(1,76) = .01$, $p = .99$ showed any significant differences between the experimental and comparison groups.

It was further hypothesized that the experimental group will outperform the comparison group on the self-efficacy measure and that within each group there will be increases from pre- to mid- to post-test. To summarize the self-regulatory efficacy data, which was taken before, during, and after the intervention, a repeated measures test was performed. Significant differences in self-efficacy were found within the groups, Wilks's $\lambda = .81$, $F(2, 65) = 7.40$, $p < .01$. The experimental group demonstrated a loss in self-efficacy from the pre-test ($M = 7.20$, $SD = 1.20$) to the mid-test ($M = 7.11$, $SD = 1.53$) and then demonstrated a large gain in the post-test ($M = 7.68$, $SD = 1.84$), which were significant at the .05 level. Table 3 shows a comparison of the means for the quantitative measures used in the study.

Furthermore, it was hypothesized that differences would emerge within the experimental group on all four post-test measures. Paired samples *t*-tests were conducted to compare differences from pre-test means to post-test means. Significant differences were found within the experimental group in metacognition, content knowledge, and nature of science knowledge. In the comparison group, significant differences were found for content and metacognition. The largest changes from pre- to post-test was found in the experimental group ($n = 33$) for content (TEMK) $t(1, 32) = 16.64$, $p < .01$ and in the experimental group ($n = 33$) for VNOS-B $t(1, 32) = 6.35$, $p < .01$. Other significant differences from pre-test to post-test found in the experimental group occurred on the MOLES-S $t(1, 36) = 2.81$, $p < .01$ and on the MONOS $t(1, 35) = 2.98$, $p < .01$. Significant differences from the pre-test to the post-test were found in the comparison group ($n = 35$)

for content $t(1, 34) = 11.96, p < .01$ and for MOLES-S ($n = 45$) $t(1, 44) = 3.41, p < .01$.

Qualitative Analyses: Study II

In an effort to gain a deeper understanding and explore possible explanations for the quantitative findings, we collected further qualitative data. The following two questions were addressed: (1) What characterizes the shared experiences of students who use EMPNOS and students who do not use EMPNOS?; and (2) In what ways do students approach activities with embedded metacognitive prompts and activities without metacognitive prompts?

Participants. After the quantitative portion of the study, focus groups and think aloud groups were randomly selected from the experimental and comparison groups. Six comparison group students and six experimental group students were chosen for the focus groups, which were conducted separately with a semi-structured protocol including questions on content knowledge, nature of science knowledge, metacognition and self-regulatory processes of learning. Six additional students from each group were chosen to re-enact one of the modules and to talk aloud about their thinking processes.

Student Products from Inquiry Units. The comparison group and the experimental groups had identical inquiry units that contained identical science content and science process skills. Within the inquiry unit, students evoked prior knowledge and shared it with the class, answered science content questions and used science process skills to make conclusions about the phenomena, and summarized their findings into "big ideas" based on the evidence found. The student products were coded using themes in the way students answer questions, and themes in the way students design scientific products such as data tables or observations. For example, codes that categorized the way students answered questions included description only, and description along with explanation. Two other researchers who were not directly involved with the project coded 80% of the student products using the code-book developed by the researcher.

Think Aloud Protocol. After the interventions, six students were randomly chosen from the comparison group and six students were randomly chosen from the experimental group and videotaped separately while they performed an investigation from the intervention. Students were asked to think aloud during the videotape in order to elicit their thinking processes during a scientific investigation from one module of the intervention. Since eighth-grade students have little experience in expressing their "inner voices," an established protocol to encourage three levels of verbal reports were used, verbalization of covert encodings, explication of thought content, and explanations of thought processes (Ericsson & Simon, 1993). Students were instructed to talk aloud about what they are thinking, and not to focus on the answer to the problem. Students were prompted at key points throughout the think aloud to continue their explanation. Two additional researchers open-coded transcripts for categories, which were grouped into themes and there was agreement among the themes as measured by $\kappa = .73$. The researchers met to discuss the coding and adjust the themes until a $\kappa = .90$ agreement was reached.

Focus Group Interviews. After the intervention, six members were randomly chosen from the experimental group and six members were chosen from the comparison group to participate in a focus group. The members of the focus groups were different from the members of the think aloud groups. A focus group could elicit more rich verbal data from the students because they would interact with each other and expand each others' ideas. The questions are semi-structured because they focus the conversation without giving up the freedom that may be needed to explore phenomena that emerges. Sample questions are (1) What was the topic of your last science class?; (2) How did you think like a scientist in that lesson?; (3) How did you act like a scientist in that lesson?; (4) How do you think science class is different from English, history or math class?; (5) How can you think about your thinking?; (6) What does it mean to you to think like a scientist?; (7) Are there other ways of thinking?; and (8) Do scientists behave differently than other people? Focus group conversations were audio-taped and transcribed using the software, Transana. The transcripts were open-coded to find emergent categories. Once verbatim statements were grouped into categories, the categories were once again grouped into larger themes. Focus group interviews were coded using the same methods as the think aloud protocols.

Qualitative Results

Student Meaning of "Thinking About the Nature of Science"

In studying the question, "What characterizes the shared experiences of students who use EMPNOS

and students who do not use EMPNOS?," a theme emerged from the comparison group that was characterized by learning content rather than thinking in a particular way. The students placed their attention on reporting content or processes, instead of seeing themselves as thinking about the nature of science. One student in the comparison group responded, "thinking scientifically means making inferences and observing everything," which reflects a scientific methods type approach to hand-on science. When probed about how science was a way of knowing, a member of the comparison group answered, "Scientists are more serious about the world. Regular people don't wonder about the world." Other students from the comparison group replied, "Thinking (like a scientist) means that you know the way you learn best," in which the student referred to the methods she used to study for a science test. The experimental group tended to answer with characteristics of scientists that were more aligned with the nature of science. Some of the student responses included, "scientists have great imaginations . . . when they don't know how to do it (show a phenomena), they try things until they can show it," "science is more than just facts, you can elaborate on them," "when you have more technology you can use it to change theories," and "the more information you learn, the better your theory." Data also indicated that the comparison group was more concerned with getting an answer to a question. When students from the comparison group would have a disagreement about the explanation for phenomena, they would call over the teacher as an authority figure to "see who was right." A student from the comparison group elaborated, "If we couldn't figure out the big ideas, we would wait for the class to show their answers or ask (the teacher) at the end. That's how we knew it was right." The experimental group was more interested in connecting their prior knowledge to their explorations in the inquiry unit. This also indicates that the experimental group related more to the process of thinking than the comparison group.

The comparison group tended to focus a step–by-step process to solve hands-on problems. A student from the comparison group states, "It works better for me if you have directions first. These labs didn't give much information about what to do. I didn't know what to do." The experimental group tended to talk more about exploring and using evidence to add to a knowledge base. One student from the experimental group talks about adding details to their explanations, "When I first started the modules, I would go back to change my answer to make it more detailed. At about the third module, I would remember the checklists and you don't go back to change your answer much." Another student explains "If I messed up, I would figure them out from my observations and from my group, and went back to change it. That is part of science." Statements from the experimental group indicate that they reflected on their performance more than the comparison group, demonstrating that they were more self-regulatory.

Student Approaches to Conducting Inquiry.

The students from the comparison group could express what they learned from the packets, but could not say why they learned the content from the packets. One comparison student responded, I "learned from the packets (the modules), but I can't say how," indicating the inability to be metacognitive. Another reported, "I was afraid that I would mess up and learn the wrong thing." When asked how scientists think differently than other professions, students from the comparison group responded, "scientists think in labs," "scientists draw on paper," and "scientists don't think differently, thinking all has a common link." Comparison group students tended to focus on the answer they were trying to get and did not have elaborate ideas about how science operates as a discipline. However, the experimental group, when asked how scientists think, responded, "put stuff together," "analyzing," "draw data tables," "do lots of different trials," "draw pictures to describe something to someone who is not a scientist," "need evidence to explain something in science," and "can't make things up." The students in the experimental group reported trying to figure out new phenomena from their prior knowledge, "I tried to figure things out from the things I knew." One student from the experimental group explained his self-regulatory process in thinking about making a conclusion, "When we had a disagreement, we kind of figured out what made sense and what didn't make sense. Eventually we all came to an agreement that we didn't do something right. Then we went back and changed it." Experimental group members also reported science as being more interactive because "you have to think of your own ideas to explain things." Students in the comparison group used the inquiry unit to work towards a single answer, while the experimental group tended to construct elaborate connections about the phenomena.

Discussion

This study used an explanatory mixed method design to test an intervention intended to teach students to be metacognitively aware of their scientific thinking, and measured potential changes in content knowledge, nature of science knowledge, metacognition, and self-regulatory efficacy. It was hypothesized that students exposed to the intervention would report a higher level of content and nature of science knowledge, metacognition, and self-regulatory efficacy. The results support the hypothesis partially, in that there was a significantly higher gain in content knowledge and nature of science knowledge for the experimental group receiving the embedded prompts than in the comparison group. Students in the experimental group had access to explicit checklists and questions, and checked their inquiry outcomes for alignment with a standard aspect of the nature of science. According to iterative feedback loop of self-regulatory theory (Zimmerman, 2000), the students who had the metacognitive prompts had more sophisticated understanding of content with which they could begin the next inquiry. Students who were not given the prompts had no check with a sample of scientific epistemology against their outcomes and had less developed understanding of the content and with the nature of science. More evidence for this is elicited from the students in the comparison focus groups as they explained that they often sought an authority, such as the teacher, to check their outcomes.

Students who were exposed to the metacognitive prompts could have understood science to be more than a collection of facts (Chin & Brown, 2000; Crawford, 2005; Crawford et al., 2000; Gijlers & de Jong, 2005; Hogan, 1999b). The gains are not likely due to long-term inner class processes because all four classes had the same science teacher for the entire year, and both the comparison group and the experimental group participated in the same inquiry activities, and there were no significant differences in the pre-tests. The only difference in the instruction was the inclusion of the metacognitive prompts for the experimental group. Students who had instruction in the nature of science could have been able to construct a broader conceptual framework on which to hang the content learned in the modules, resulting in a gain in both content and nature of science knowledge.

No significant gains were reported between the experimental group and the comparison group in metacognition or self-regulatory efficacy in the quantitative portion of the experiment, but were found in the qualitative portion of the experiment. This result could be due to the method of instruction for the embedded metacognitive prompts. Due to the dual role of the teacher/researcher, the first three phases of the metacognitive prompts were done in cooperative groups, and the last phase, the self-regulation phase, of the metacognitive prompts were given as an independent homework assignment in order to avoid confounding variables attributed to teacher/researcher coaching. Students were not directly questioned about the metacognitive prompts; rather they were treated as additional direction to work in groups and complete the last set of prompts as homework. The students in the experimental group may have experienced higher levels of self-regulatory efficacy if they were exposed to more explicit strategies such as keeping track of progress in the units (Kitsantas, Reiser & Doster, 2004; Weinert, 1987). In addition, the measures of metacognition and self-regulation may not have been developmentally appropriate for students in eighth grade. There has been evidence that self-regulated learning has significant developmental differences between fifth, eighth, and eleventh grade students (Zimmerman & Martinez-Pons, 1990). Zimmerman and Martinez-Pons found that developmental increases in students' use of self-regulation processes corresponded to developmental increases in their verbal and mathematical self-efficacy. Since metacognition is a subset of self-regulation, the metacognition measures have the same issues. Students may have been able to self-regulate their learning, but may not have been able to explicitly talk about the mechanisms in their thinking. Additional study of verbal and mathematical self-efficacy may shed light on this outcome in future studies.

Within the groups, it was hypothesized that differences would occur within both experimental groups and comparison groups on all pre- and post-measures. Significant differences were found within the experimental group on metacognition, content knowledge, and nature of science knowledge. Significant differences were found within the comparison group on metacognition and content knowledge. Gains in both groups in metacognition could have occurred because of the design of the inquiry units. All four of the units had a component of constructivist learning as students were required to observe phenomena, record behavior and speculate on a personal theory of why the phenomena happened. Students were also required to

work in groups, which resulted in active discussion of ideas. Student metacognition could have increased within both groups and not shown differences between groups because they were required to pose and defend their own ideas within their groups in the inquiry unit. Students were required to think about their thinking in order to express it coherently and logically defend their original ideas. The gain in content knowledge for both groups could have also occurred because of the design of the inquiry unit. Since students had to construct their explanations for phenomena, they had ownership of the content and were able to make the content fit into current conceptual frameworks (American Association for the Advancement of Science, 1993; National Research Council, 1996). The gain within the experimental group in nature of science knowledge could have been due to the extended exposure to the concepts of the nature of science. Because the students had access to checklists and questions regarding the nature of science, they had easier access to the language and ideas that connect their actions to nature of science, resulting in an increase in nature of science knowledge.

It was hypothesized that the experimental group would outperform the comparison group on the self-efficacy measure, which was not supported. There were significant differences within each group, but there were not significant differences between the groups. The comparison group's self-efficacy steadily increased while the experimental group's self-efficacy dipped down when the mid-test was given and rose to a high for the post-test. This could have occurred because the experimental group was asked to justify their thinking through the checklists and prompts. Initially, the students had inflated self-efficacy because they did not have explicit experiences with the nature of science. When the students in the experimental group experienced the self-reflection with the checklists and questions, their self-efficacy in learning dropped because of their lack of experience with addressing the nature of science. As the students in the experimental group felt supported by the developmental phases of the self-regulatory processes, the self-efficacy in this group rose above the comparison group (Zimmerman, 2000).

It was hypothesized that there would be a positive correlation among all five measures, which was partially supported by these data. The three highly correlated measures were the VNOS-B and TEMK, the MONOS and TEMK, and the MONOS and MOLES-S. The VNOS-B and TEMK may have correlations because the content test assessed students' explanation regarding phenomena and their personal theories behind the mechanisms of the phenomena. Knowledge of the nature of science is important in being able to explain personal theories behind phenomena (Duschl, 1990). The MONOS and TEMK have correlations because the MONOS is based on the seven aspects of the nature of science (Lederman, 1992; McComas, 2005), which forms a foundation with which students can understand content regarding physical phenomena. In addition, the performance phase of the self-regulation required students to summarize their findings into two or three encompassing ideas which enacted metacognition in the students. The inquiry units given to all groups required students to be metacognitive about their findings in the hands-on portion. The MONOS and MOLES-S were found to correlate highly because they are both instruments that explore metacognition.

The focus group and think aloud transcripts, and student products showed that students who used the EMPNOS (the experimental group) talked more about the development of their knowledge than the comparison group. The experimental group tended to speak about their explanations about why the phenomena occurred (Bell, Lederman, & Abd-El-Khalick, 2000), whereas the comparison group could not provide any explanations. The comparison group tended to focus on listing the content their learned when asked about how they thought in a scientific way. The experimental group also had more frequent discussion about the need for empirical evidence that backed up their personal theories. The comparison group did not talk at all about empirical evidence, even though they expressed concern with getting the "right" answer. The experimental group used the prompts as a guide for self-reflection and was able to connect prior knowledge to performance more fluently.

Limitations of this study are the convenient sample size, and the lack of minorities in the sample. Future studies should expand the student sample to include more minority participants, add more self-regulatory processes into the developmental intervention, and use questions from a national examination to the TEMK in order to compare the study sample to a national sample.

Implications for Instructional Practice

Teaching science as a series of disconnected facts has been shown to be ineffective (Chin & Brown, 2000; Crawford, 2005; Gijlers & de Jong, 2005;

Hogan, 1999a) and does not help students form ideas about how scientific knowledge is created and verified (Clough, 1997; Duschl, 1990). Often, teachers have only a surface understanding of the discipline of science (Abd-El-Khalick & Akerson, 2004; Akerson et al., 2000; Bianchini & Colburn, 2000; Chin & Brown; Nott & Wellington, 1998) and need additional resources to teach about the nature of science. Embedded metacognitive prompts based on the nature of science can aid in connecting content knowledge to nature of science knowledge resulting in an increase in understanding in both areas (Herbert, 2003). Lessons constructed with prompts that encourage students to compare their understanding against a known epistemology adds a dimension of learning that teaches science as a way of knowing. When we teach science for all, we should understand that not all students have an innate ability to see science as a way of knowing and therefore, must be explicit in exposing scientific epistemologies.

EMPNOS provides a tangible pedagogy that can be easily inserted into previously developed lesson plans. Teachers can choose the aspect of the nature of science that is best illustrated in a particular topic, and locate appropriate places to insert the developmental prompts. Using the EMPNOS checklists and questions, teachers can insert phases one through four of the chosen nature of science aspect into their lesson plans. Teachers can use EMPNOS to scaffold understanding through a developmental process and enrich student understanding of both content knowledge and knowledge about how the content is developed and verified in the scientific community (DeSautels & Larochelle, 2006). The prompts may also cause some teachers to reflect on their current lesson plans because if the prompts are inserted into lesson plans that do not use inquiry, the students will not have the ability to answer the questions. In this way, the prompts could help some teachers realize that they do not give the students the opportunity to reflect on their thinking. The intervention is cost effective and complements teachers' current curriculum.

Further development of metacognitive prompts may lead to a tangible tool to promote learning progressions in the nature of science. The reading level of the prompts can be adjusted for grade bands such as K-2, 3-5, 6-8, and 9-12 and used to gather empirical evidence regarding the appropriateness of each of the seven aspects of the nature of science for the grade bands. For example, the tentativeness of science may not be developmentally appropriate to teach to kindergarteners, but students at this grade level may understand the creative aspect of science. As students get older, other aspects of the nature of science can be introduced when it is suitable. Just as content is developed through learning progressions (see *Benchmarks for Scientific Literacy*), the prompts may be one tool that can be used to identify the grade level at which students are prepared to understand aspects of the nature of science.

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Journey toward Teaching Mathematics through Problem Solving

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Teaching mathematics through problem solving is a challenge for teachers who learned mathematics by doing exercises. How do teachers develop their own problem solving abilities as well as their abilities to teach mathematics through problem solving? A group of teachers began the journey of learning to teach through problem solving while taking a Teaching Elementary School Mathematics graduate course. This course was designed to engage teachers in problem solving during class meetings and required them to do problem solving action research in their classrooms. Although challenged by the course problem solving work, teachers became more comfortable with the mathematics and recognized the importance of group work while problem solving. As they worked with their students, teachers were more confident in their students' abilities to be successful problem solvers. For some teachers, a strong problem solving foundation was established. For others, the foundation was more tentative.

Learning mathematical knowledge through the act of problem solving is one of the premises of the *Principles and Standards of School Mathematics* problem solving standard (National Council of Teachers of Mathematics [NCTM], 2000). As students use technology to explore a topic, try multiple ways to solve a task, or pose new questions based on their investigations, they are actively involved in problem-solving processes. The phrase "teaching through problem solving" is used to describe instruction in which teachers engage their students in problem-solving processes with the goal of learning mathematics content (Lester & Charles, 2003; NCTM; Van de Walle, Karp, & Bay-Williams, 2010) and is a foundational component of mathematics reform (Hiebert et al., 1996; NCTM, 2000). As students, today's teachers learned mathematics in classroom environments that were not characterized as problem-solving environments. Instead, the teacher-centered classrooms focused on computation skills and fact mastery drills. When asked to apply the drilled information to word problems, the teachers as students had some difficulty. Due to improvements in the pre-K-12 mathematics curriculum, teachers are now asked to teach content they did not learn in elementary school and to use processes they did not experience as learners.

Teaching a curriculum they did not learn and using processes they did not experience are big challenges for teachers. Additional pressures such as preparing for high-stakes standardized tests, wanting success for all students, and helping students who lag behind make it difficult for teachers to focus on teaching mathematics for understanding (Herrera, 2005). In an interview with Herrera, Burns described how today's mathematics education should provide students with opportunities to reason and think: "Education should imbue curiosity and a love of learning. We want students to think and reason and solve problems in all areas of life. If the only reason we are studying a topic or asking a question or doing an exercise is for the test, it doesn't make sense" (p. 7). Since teachers generally teach how they were taught (Ball, 1990; Thompson, 1984), how do teachers learn to teach students to think, reason, and solve problems in mathematics when teachers learned mathematics by doing exercises? How will teachers implement an innovative change in the form of teaching mathematics through problem solving?

Research studies document that teachers' beliefs influence their instruction (Nespor, 1987; Philipp, 2007; Thompson, 1992). A movement toward teachers teaching differently than they were taught begins with preservice courses designed to challenge teachers' beliefs through activities such as "drawing a mathematician" (Mewborn & Cross, 2007), examining videotapes of standards-based classrooms (Chval, Lannin, Arbaugh, & Bowzer, 2009), and doing mathematical problem solving (Namukasa, Gadanidis, & Cordy, 2008/2009). Researchers who examined changes in preservice teachers' beliefs resulting from completing a course designed to engage teachers in

problem solving–based instruction as students and as teachers found teachers' beliefs became more aligned with recommendations for standards-based classrooms (Hart, 2002; Swars, Smith, Smith, & Hart, 2009; Timmerman, 2004; Wilkins & Brand, 2004). The teachers' resulting change in beliefs supported Ferrini-Mundy's (1997) finding and Mewborn and Cross' (2007) conclusion that an important component of teachers shifting their beliefs about mathematics reform ideas is their need to experiment with implementing reform-based instruction.

The importance of teachers experimenting with reform-based instruction is also seen in studies that focused on inservice teachers' actions while implementing standards-based instruction as professional development project participants. By experimenting with standards-based instruction, teachers showed their ability to assume the role of facilitator in the teaching and learning of mathematics (Borko, Davinroy, Bliem, & Cumbo, 2000; Brahier & Schäffner, 2004; Crespo & Featherstone, 2006; Kersaint & Chappell, 2001; Smith, 2000; Sullivan, Griffioen, Gray, & Powers, 2009). These studies identified situations that aided teachers' implementation of reform-based instruction. The first five studies included opportunities for teachers to do mathematical problem solving before teaching mathematics through problem solving. Being able to dialogue with colleagues about their problem-solving experiences and about their problem solving based instruction aided their understanding of the process and provided them with ongoing support as they tried to implement change in their classrooms (Borko et al.; Brahier & Schäffner; Crespo & Featherstone; Kersaint & Chappell; Smith). The importance of teachers sharing their instructional experiences with other teachers was also seen in the work by Sullivan and his colleagues (2009). For all six studies, in addition to dialoguing with other teachers, reflecting on the process was also a valuable component of teachers' development as problem solving–based teachers.

Helping teachers learn how to teach mathematics through problem solving has been part of the first author's ongoing work with elementary teachers. The context for much of this individual's work with teachers was a graduate-level methods course. Although a course represents a short-term commitment to professional development, it is a situation to which many teachers have access. In addition, since structure alone does not determine the value of a professional development opportunity (Ball, 2002), a course setting has the potential for providing teachers with experiences that will act as catalysts for their development as teachers. In particular, this study examined teachers' experiences in a graduate course designed to facilitate their learning to teach mathematics through problem solving. The research question that guided this study was: What are the successes and challenges for teachers as they engage in an action research project based on teaching mathematics through problem solving?

Methodology

Setting

The professor's sixth time to teach a three-credit graduate course titled Teaching Elementary School Mathematics provides this paper's context. The professor initially designed the course to enable teachers to become better problem solvers and to encourage them to teach mathematics through problem solving in their own classrooms. While teaching the course, the professor observed that teachers became better problem solvers, but they typically were skeptical that a problem-solving approach would work with their students. Based on her action research work, the professor redesigned the course two years prior to this study. Reading research and engagement in problem solving during class meetings were not sufficient for teachers to have an understanding of problem solving as a way of learning. Thus, teachers also engaged in an action research project in which they taught mathematics through problem solving. Through this process, it was hoped that the teachers would make connections between their own learning and their students' learning.

The intent of the redesigned course was to help teachers learn problem solving, implement effective teaching through problem solving, address initial challenges that might arise when implementing problem solving, and make sense of social constructivism as students and as teachers. The "fostering a community of learners" principles of action, reflection, collaboration and community that "seem to be grounded solidly in mathematics education reform" (Sherin, Mendez, & Louis, 2004, p. 211) were evident throughout the implementation of the redesigned course.

Participants

The participants were 41 teachers taking an elementary mathematics methods graduate course. The 41 teachers were in one of two sections offered during a five-weck summer session that overlapped with the

last three weeks of the teachers' school year. Five teachers were pre-kindergarten and kindergarten teachers. One teacher was a middle-school Spanish teacher, one was a secondary mathematics teacher, and one was only teaching science. Seven teachers were not yet teaching in their own classrooms; some substitutes taught whenever possible and one worked at another job, having just finished student teaching. The other 26 teachers taught mathematics in grades one to six. Approximately one-third of the group of 41 taught in a district that had adopted problem-based curriculum materials the previous year, either *Investigations* (Russell, Tierney, Mokros, & Economopoulos, 1998) or *Connected Mathematics* (Lappan, Fey, Fitzgerald, Friel, & Phillips, 1998). This group of teachers participated in a one-week inservice the previous summer to prepare them to teach the new curriculum.

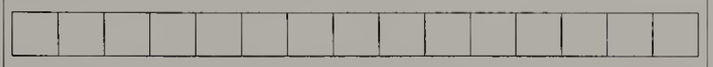
Design of the Course: Teachers as Problem Solving Students

Teachers read and discussed two textbooks, *Children Are Mathematical Problem* Solvers (Sakshaug, Olson, & Olson, 2002) and *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics, 2000). In the first text, mathematical problem situations posed for the reader to solve were followed by questions one might ask children as they solved the problems. The textbook also contained examples of how other children solved the problem and what the authors learned from analyzing children's work. The second text contained NCTM's recommendations for underlying principles of school mathematics and for mathematics learning standards. This set of principles and standards was adopted as the new state standards for mathematics in 2005.

Beginning with the first class session and continuing for each meeting, at least an hour was devoted to problem solving. During each class session, the professor provided mathematically rich problem situations where the teachers explored a problem on their own until teachers felt comfortable enough with the solution process to work with their own students (see Figures 1 and 2 for example problem situations). The length of time varied according to the type of posed problem. Typically, students worked individually for 5 to 15 minutes before working in small groups. After the groups negotiated a shared understanding of the problem and discussed the range of approaches tried, groups talked either with other groups or with the whole class. Finally, the whole class debriefed, sharing

The Problem

How many rectangles appear in the figure below?



Sakshaug, Olson, and Olson (2002, p. 10)

Figure 1. How many rectangles?

solutions, elaborating on the mathematics, and discussing roadblocks. For several problems, between the individual and the group brainstorming, class members discussed how much they understood in isolation. Afterward, the group examined whether there was a change in individuals' levels of understanding as a result of working with others in the group.

During the problem-solving portion of the class, teachers either completed one problem, several problems, or took the problem with them to examine before the next class. After completing the problem-solving portion of class, the group deconstructed the professor's approach to teaching the lesson. The group discussed where the mathematics was in the problem situation. They talked about what made the problem challenging and what it meant to be successful with the problem. They also talked about how the problem fit with their teaching (or not) and how their students might respond to the problem. During the next class period, a follow-up discussion occurred based on a problem-solving text-reading assignment that described how children solved the problem.

Design of the Course: Teachers as Action Researchers

As a course requirement, teachers did an action research project in their classrooms. The professor made accommodations for those teachers not teaching mathematics or not teaching in their own classrooms. For example, one teacher taught science only. In his class, he selected integrated problems that addressed science and mathematics ideas. Another teacher was not the mathematics teacher for her middle-school team. She collaborated with and had the support of the team's mathematics teacher as she engaged in mathematical problem solving with their students. After the first week of class, the professor asked the teachers to choose one problem from the problem-solving text and pose it for their own students to solve. The chosen problem was one they had solved or read about in their

The Problem

Doubling Doughby created a mixture of dough that when placed in a warm oven doubles in volume every minute. He designed a pan, called a Doughby Pan, to hold the dough. He noticed that when a Doughby Pan full of dough was placed in the oven, it would exactly fill the oven in one hour.

Doubling Doughby usually had two ovens into which he placed a Doughby Pan full of dough, but one day one of his ovens was not working. He then had to place the two Doughby Pans full of dough into one oven. How long will it take for two Doughby Pans full of dough to fill the single oven?

Sakshaug, Olson, and Olson (2002, p. 14)

Figure 2. Double that dough.

assigned readings. The professor asked the teachers to do this a second time, after the second week of class, which was the second-to-last week of their school year. By doing problem solving in the graduate class at approximately the same time teachers taught the problem in their classroom, the community gathered comparative data and did action research to determine how their students would solve the same problems. It was hoped that teachers' concerns about whether their students could solve the problems would be alleviated through this process and that the teachers would experience similar results to those found in the research readings.

Data Collection and Analysis

The teachers' written reflections on their action research problem-solving projects was the primary source of data for depicting teachers' work as action researchers. Specifically, after teaching each problem, the teachers responded to these prompts: (1) why I chose this problem; (2) children worked: alone or with others; (3) what I did to present the problem; (4) what the children did when they were solving the problem; (5) what the children learned; (6) what surprised me; (7) what I would do differently if I taught this problem again; and (8) how the problems were like/unlike what the authors reported in the class text. The professor's notes on class discussions of teachers' work as action researchers generated anecdotal information that expanded teachers' written reasons and illustrated whether connections were being made to course work. Also, the class discussions brought to life teachers' descriptions of children's actions. The teachers' problem-solving classwork provided information about their strategies, mathematical discussions, group work interactions, and reflections on the process. The professor recorded notes on these ideas as she looked for possible influences the teachers' problem-solving work had on their teaching through problem solving. The teachers' final written reflections about the graduate course content and components provided information that supported the results found in other data sources.

The professor did initial data analysis by examining her notes on class problem-solving work and project discussions. Through this process, she identified successes and challenges teachers experienced as action researchers teaching mathematics through problem solving. The professor responded in writing to teachers' written reflections. A mathematics education specialist who did not know or interact with the class but knew the course content also analyzed the written reflections. Independently, the professor and the analyst read the teachers' action research reflections item by item, identifying categories for each item and characterizing teachers' actions. They made category and characterization comparisons and then reexamined the data to determine if either new categories or new characterizations were needed. The reexamination process also included a review of the professor's class notes. Once the categories and characterizations were finalized, the researchers looked over the analyzed data for trends describing teachers' successes and challenges as they taught mathematics through problem solving.

Results

The teachers engaged in a graduate class that tested their abilities as mathematical problem solvers and as action researchers teaching mathematics through problem solving. The analyzed data showcased the teachers' journey of learning to teach mathematics through problem solving by identifying their successes and challenges as they implemented their action research projects and related their work to course ideas. The examination of teachers' successes and challenges occurred in these contexts: (1) comfort

level with mathematics; (2) selection of problems; (3) instructional components; (4) impact on students; and (5) beliefs about the process.

Comfort Level with Mathematics

The first picture of teachers' comfort level with mathematics was seen in their class problem-solving work. Most of the teachers struggled while working individually on the problems. When small groups came together to continue discussing the problems, there was a much greater level of success at understanding the problem and selecting strategies that led to solving the problems. Teachers' mathematical understandings were facilitated by their group work. In many instances, teachers said they were not able to solve a problem or really understand some aspects of it until they talked with others. Group members were asked not to tell individuals how to think about the problem. Rather, the group was asked to make sense of what each individual was not able to do in the initial individual exploration.

A second view of comfort level with mathematics was seen in teachers' discussions of the problem solving text readings. For each problem in the text, a range of generated solutions was shared, including some correct and some incorrect ways to solve the problem. Most teachers successfully identified solutions and accurately described the mathematics. However, six teachers were challenged by this process and could not tell where the actual answer occurred in the narrative. For example, when the teachers were solving a problem in which they were asked to find the number of possible sandwich combinations, based on a variety available toppings (13 sandwiches had cheese, 14 had salami, 13 had tomato, 8 had cheese and tomato, etc.), they were not able to follow the reasoning in the solution process and could not tell whether they had successfully found all the possible combinations. Although every problem section included at least one accurate solution, several teachers wished the book had an answer key.

More information about teachers' comfort level with mathematics was seen in their work as teachers. As part of their research, teachers described why they selected a problem, how they presented the problem, and what children learned. The analysis of these descriptions indicated that 23 of 41 teachers were comfortable with the problems' mathematical ideas. Teachers accurately described mathematics topics as they reflected on work with their students. A strong comfort level was suggested when teachers described the mathematics in terms of mathematical concepts and problem solving, reasoning, and communicating processes. Part of this description included teachers' ability to explain their understanding of the selected problem's mathematical purpose. Being able to see that students' varying approaches to a problem addressed the key mathematical ideas also indicated teachers' strong comfort level with mathematics. Sixteen teachers' writings and discussions indicated teachers were inconsistent in their comfort level with the mathematics. For example, in portions of their solution explanations, teachers demonstrated their ability to accurately describe the mathematics and explain students' mathematical work. In other aspects of their writings, teachers' comments were mathematically incorrect, showed they did not understand the mathematical purpose of the problem, or only focused on mathematics as a procedure. In the case of the remaining two teachers, the substance of their responses made it difficult to determine whether they were comfortable with the problems' mathematical content. Their problem-solving work in the graduate class supported the notion that these two teachers were not comfortable with the mathematics.

Selection of Problems

The teachers' reasons for selecting a problem as their instructional basis illustrated where they were at in their thinking about teaching mathematics through problem solving. Teacher 7's explanation for choosing the "How Many Rectangles" problem illustrates how teachers identified multiple reasons such as mathematics content, mathematics processes, and classroom goals for selecting their problems:

> Teacher 7: I chose this problem because I thought it had some great concepts involved in it. I thought the students would have fun solving the problem, and would ask some great questions. Even as seventh graders, this problem would help the students recognize patterns, and explore number theory. I also chose the problem because the students would be able to work together, and improve their communication skills in math.

Twenty-six of the 41 teachers chose a given problem based on the problem's mathematics content of the problem. Although most of these teachers identified broad content categories such as geometry, patterns, and combinations rather than specific concepts or skill development such as identifying shapes within shapes

or estimating sums, they clearly recognized the role mathematics played in the problem solving process. Other non-mathematical reasons for problem selection included teachers were intrigued with the problem, were curious about what strategies their students would use, identified the activity as a great center activity, and wanted to start with a doable problem.

Instructional Components

The teachers' instruction provided evidence concerning their abilities to teach mathematics through problem solving and characterizing their journey toward learning to teach mathematics through problem solving. The instructional discussion focused on three areas: (1) how teachers presented the problems to their students; (2) how children worked with the problems; and (3) what teachers would do next time they taught with these problems.

How Teachers Presented the Problem to Their Students. Presenting the problem was described as the process by which teachers introduced children to and engaged them in the problem. Making sure the problem remained a problem and did not become an exercise was a tenet of teaching through problem solving. Thirty of the 41 teachers maintained the integrity of both problems that they used. When implementing problems, many teachers utilized the process modeled in the graduate class by the professor—give the problem and with virtually no discussion direct students to work the problem. Although some teachers needed to have a brief class discussion at the outset, their writings indicated their discussions were about making clarifications and not about telling the students how to do the problem. Teacher 8's example illustrates how initial discussions were used to make sure students understood how to make cube towers with the unifix cubes but that did not tell them a strategy for solving the problem:

> Teacher 8: I read aloud the story problem to the class and then showed how to connect the cubes to make an example of a two cube tower. I passed out the cubes to pairs of students and had one person be the recorder and one person be the builder. . . . The students were asked to make all of the two, three, and four cube towers that they could think of and record them on paper.

During problem introductions, teachers used additional strategies to make them accessible to students while still maintaining the problem's integrity. Teachers set up the problem by modeling an activity that was the basis of the problem. The modeling process was appropriate because the mathematics resulted from analyzing the activity's results rather than from the process needed to do the activity. Teachers also presented problems by providing a context for the problem (e.g., embedding it in a real-world situation such as patterns on children's clothing or a storytelling situation). Setting a context enabled the students to make connections within mathematics or to other subject areas. As part of the problem setup, several teachers gave students specific materials to use such as cubes, graph paper, geoboards, and shape cutouts. Some teachers took a more open-ended approach by providing a range of materials from which students selected what to use.

Teachers' challenges in presenting problems were seen in those situations where their actions took away the problem-solving situation from the children by being too directive. Some teachers did this by giving children one strategy to use—for example, a teacher told the students to use a table to solve the problem. Teachers also minimized the problem solving when they identified the key information for solving the problem. For example, in a problem where it was important for students to recognize that different-sized squares were hidden in a figure, the teacher told the students to look for hidden squares in their figure. In a few situations, teachers minimized the problem solving focus by presenting the problem as something fun to do without making a reference to any other purpose. While it is always a goal that mathematics be interesting and fun, the teachers were asked to select problems intended to further their students' understanding of mathematics content.

How Children Worked with the Problem. Determining whether children were participants in a problem-solving environment was the focus of the examination of how children worked with the problem. In particular, three areas characterized the environment: (1) whether or not children worked in groups; (2) how they worked in groups; and (3) how teachers interacted with the children.

The instructional decisions for 31 teachers indicated they recognized the importance of small-group interaction when children solved open-ended problems. Twenty-three of these teachers showed a strong commitment to using groups as they had their children work in groups for both problems. Eight teachers used the group process for one of the problems, but either

made the group work optional or directed the children to work alone for the other problem. For the remaining 10 teachers, the instructional focus was on children working individually. One teacher's description indicated that it was appropriate for her preschool children to work by themselves. Some of the 10 teachers gave children a choice of working alone or with a partner, indicating they were aware of the importance of small-group interaction. Since these teachers did not make instructional decisions to put children in groups suggested the teachers struggled with how to implement their knowledge.

The physical organization of the children was only one aspect of working in groups. It was equally important to examine the occurrences within the groups. For some of the teachers, student interaction meant sharing their thinking while trying to solve the problem together. An example from Teacher 2 shows how students worked together to solve problems:

> Teacher 2: As the children were working on the problem, I walked around to listen to their reasoning and see what kind of strategies they were using to find a solution. Since they were grouped in fours, some role played and pretended that one person was handout out the cookies and the other three were the receivers. I also heard excellent conversations around which strategies to use (draw pictures, charts, tally marks etc . . .) and explanations as to how they arrived at the answers.

For other teachers, student interaction took on the form of peer-tutoring where either a strong student told the group how to do the problem or students chose to work in groups only to see if they got the same answer. The peer-tutoring use of groups did not encompass the notion of shared learning.

Identifying who directed the learning during teacher–children interactions determined whether teachers implemented a problem-solving approach. Teachers who successfully implemented a problem-solving approach were inclined to use strategies promoting children's mathematical thinking. One such strategy was the use of a "think-pair-share" format when children worked on the problem. Once children had time to generate their own ideas for working the problem, they compared their ideas with a partner before participating in a class discussion. Some teachers used a variation of this strategy by having children individually try the problem and then discuss strategies in small groups without having a class discussion. In either case, the focus was on children leading the process for determining feasible strategies. In a few cases, teachers' observations during individual work time enabled them to strategically assign children to groups in order to maximize the discussion. The power of students working individually and then working together to solve the problem is seen in Teacher 4's observations of his students working the "Counting Squares" problem:

> Teacher 4: While the students worked alone, they were very quiet and very into simply counting. . . . I did not see any charts or tallies, more so students pointing with their fingertips and writing down the numbers they came up with. After some students shared their answers and they were obviously different from others, I began to notices students' eyes widening and realizing that there was more to it than they initially thought. . . . After students were able to get together, it was neat to watch them demonstrate to their partners where they thought the squares were. When students saw other students' sheets, they were amazed at what they had missed!

One of Teacher 4's students summarized the importance of students working together by stating "It was harder to work alone because I wasn't able to bounce my ideas off of anyone."

Teachers applying the problem-solving approach successfully either posted questions to small groups or to the whole class to facilitate children's thinking. As children responded, they explained their strategies, compared their strategies with others, described their conclusions, defended their thinking, and determined whether their strategy would work for a variation of the problem.

Teachers challenged by teaching mathematics through problem solving tended to miss opportunities for encouraging children to think mathematically. One occurring situation was when teachers needed to tell children the relationship present in the problem rather than letting children identify unfolding relationships during their explorations. For example, in a problem where it was important for students to determine whether a square was a rectangle, the teacher led a discussion on this relationship before students started working on the problem. These teachers did not see that making things easier for their students minimized

children's experiences. For some teachers, their decision to have children work alone throughout the problem meant that the teacher became the children's only sounding board, maintaining the air of authority. Other teachers recognized the importance of teachers not being the authority figure that directed children's learning. The manifestation of this recognition, however, was often in the form of giving general feedback like "try harder" or deciding not to guide a discussion. They did not realize that they could give feedback and ask questions that would promote children's thinking.

What Teachers Would Do Next Time They Taught with These Problems. Teachers' description of what they would do next time they taught with these problems provided additional insight to teachers' comfort level with the problem-solving process. Almost all teachers made references to better implementing the process of teaching mathematics through problem solving. Some exceptions were when three strong problem-solving teachers stated they did not need to do anything differently next time and two other teachers indicated the need to implement a more narrow view of the problem-solving process.

Teachers' ideas for better implementing the process focused on providing opportunities for student-driven work. As illustrated by Teacher 12's comments, teachers identified whether different manipulatives needed to be provided to students and how to better foster student thinking:

> Teacher 12: When I teach this problem again, I will provide actual 3-dimensional examples of the objects for students to touch as they work at solving the problem. I would also like to ask my students to explain, in writing, how they came to their answers.

As teachers became more comfortable with using manipulatives, they talked about making them more available for the students to decide which manipulatives they would use when solving problems. Teachers also recognized how questioning would encourage more student discussion. For some teachers, it meant using questions during their discussion. For others, the focus was on expanding their use of questions by identifying specific probing questions. Teachers also would promote more student discussion by either having students work with a partner for the whole time or by having them initially generate their own ideas before comparing ideas with a partner. Supporting the open-ended nature of the problems, teachers also said they would encourage students to find different ways to do the problems. Teacher 28's description of what she would do differently exemplifies how teachers realized the need to provide more opportunities for student engagement by using pairs and by looking for multiple solutions:

> Teacher 28: If I did this problem again, I think I would have them do it in pairs to work on their communication skills and problem solving with another person. I would be curious to see what other combinations of fences they would come up with if they worked with other kids.

In addition, teachers recognized that problem-solving experiences take time to implement and that they would spend more time on the problems the next time they taught them.

When describing what to do next time, 15 teachers stated they would change their approach and make it more directive. For example, teachers would begin with a mini-lesson that taught the children the vocabulary and the strategy they needed in order to solve the problem. As a result, they changed the problem to an exercise to be practiced. A closer look at these 15 teachers' responses identified conflicting actions in 14 situations suggesting that these teachers understood part of the problem-solving process but not all aspects of it. As an example, Teacher 33 is supportive of the problem-solving process when she identifies using groups so that students can work together to solve the problem, but she minimizes the process when she states that they would do together a problem similar to the task before she gave them the problem-solving task:

> Teacher 33: Due to time constraints, we did not get to break the children into small groups, and I think this would have benefited those that had shut down. I would allow the students to pair up in groups of two to four to exchange ideas on how to solve the problem. I think they would have persisted longer if they had someone to talk the problem out with at the time. . . . And in order to open the lesson, I would have done a similar problem together with the whole group.

In addition, teachers stated they needed to use probing questions in order to promote student learning.

Impact on Students

Teachers' identification of the problem-solving process' impact on their students was a key component of teachers' action research projects. A positive impact was visible as teachers described their students' attitudes, use of processes, learning of mathematics, and unexpected successes. Students' enthusiasm about and determination for doing problem solving was evident throughout teachers' class discussions about their projects. When teachers described what students learned by engaging in problem solving–based instruction, all teachers made references in at least one description to the processes students used. Teacher 3's description highlights the type of processes teachers identified, such as using strategies, reasoning, working with a group, and communicating:

> Teacher 3: I think the children learned first and foremost that they already knew some strategies for solving the problem. They also learned how to show/prove their work in many interesting ways. They learned how to use each other's strengths to help them solve problems. They also learned how to display their work for others using the overhead and the chalkboard.

When referencing the strategy use, teachers stated that either students used a specific strategy like looking for a pattern or they recognized that various strategies were feasible. In addition to talking with others, students learned to communicate mathematically by drawing pictures and writing. When teachers described student learning, only 23 of the 41 teachers included references to mathematics topics. Sample topics included patterns, remainders, shapes, and fairness of games.

To characterize students as successful problem solvers, teachers considered students' attitudes, use of processes, and gained mathematical knowledge. Teachers realized, however, the power of teaching mathematics through a problem-solving process while describing observed unexpected successes. Comparing students' problem-solving experiences with their own problem-solving experience provided the first context for teachers to talk about the unexpected successes. While learning about themselves as problem solvers, teachers described how challenging they found the problems. As teachers used many of these same problems with their students, they commented that their class discussions were remarkably like the ones in the graduate class. In several instances students had as much or more success than the teachers did.

Which students were successful was the second context for teachers' observations of unexpected successes. As teachers discussed and described the results of their action research projects, they highlighted how the problem-solving process made mathematics accessible to children who typically were least interested or least motivated to participate due to past experiences in more traditional mathematics classrooms. For some teachers, the unexpected successes were based on the observations that all of their students had success with a given problem. Teacher 27's description about what surprised him about his students' work is an example of all students being successful:

> Teacher 27: What surprised [me] most was that all my students completed it and the majority got it correct. I have a very tough group this year and to get them to do things is like pulling teeth. But I think overall they finally saw that each person can have their own way of doing things but that a common task can be completed just the same.

For other teachers, the surprise came from situations such as the usually unmotivated student who worked on the problem the whole class period and the "weaker" student who took on a leadership role in guiding his or her group to successful outcomes. An example from Teacher 26's classroom illustrates how problem solving gave a student who usually struggled with mathematics an opportunity to be a leader:

> Teacher 26: I was very surprised that one of my students who struggles with math got it right away. She figured out that she could add 15 + 14 + 13 + . . . + 1 to get 120. She couldn't understand what was taking everyone else so long. When I placed them in groups, I put this student with children who did not arrive at the right answer. For one of the first times ever, she was able to share her success with her classmates.

Teachers did not characterize the problem-solving process as having a negative impact on students. They did, however, identify situations that were frustrating to them. The situations occurred as teachers described

what children learned and what surprised them about the process. For one problem, six teachers indicated either they were unsure about what their students learned or whether their students learned much. For the teachers that elaborated on their conclusions, some did not recognize all of the mathematics specifics in their descriptions and others explained that learning occurred only if children completely solved the problem. As seen in this example, Teacher 28 associated strong learning with problem completion and did not recognized that students were learning to distinguish between squares and rectangles and to see rectangles within rectangles:

> Teacher 28: I don't think the children learned a great deal from the problem. I don't think the problem was waste of time though. They did work on the perseverance skills. The kids did get to practice rote counting and identifying rectangles. They were all able to find rectangles that involved 2 and 3 squares, but they didn't figure out that they could make rectangles with 4 or more squares.

When describing what surprised them about the process, 24 teachers identified challenging occurrences. Teachers were surprised that students had trouble with the mathematics content. Teacher 15's observation illustrates this scenario:

> Teacher 15: The one thing that surprised me was that none of them knew how to deal with remainders, even those students who excel in math and problem solving. However, during our study of division with remainders, we always just got our answer of a number with a remainder, we never did anything beyond that point. I was surprised that none of them tried to be creative in how they dealt with the remainders though.

Teachers were also surprised when students did not use the obvious strategy such as comparing scale pictures or using an organized list and when they took so long to complete the problem. Although teachers voiced challenges with the process, they also demonstrated they could address these challenges when teaching these problems next time. The situation also existed in which teachers made positive comments for one of the problems and frustrating ones for the other, suggesting the problem rather than the process challenged teachers.

Beliefs about the Process

Teachers' beliefs about teaching mathematics through a problem-solving approach were determined by their class discussions, action research written reflections, and final course written reflections. When the action research project was first assigned, many teachers raised concerns about doing the problems with their students. Even after reading and discussing problem-solving text narratives in which various-aged children were successful in a problem-solving context, several teachers were still skeptical about the process. For some teachers, the skepticism lessened as they developed as problem solvers while working with group members. For other teachers, the change began as they observed their children learning mathematical ideas through problem explorations. By the time teachers completed the action research project, all 41 teachers demonstrated at least some belief in the power of the problem-solving approach for teaching mathematics. Students working together is a key component of mathematics problem solving. As exemplified in Teacher 5's final course reflection about students' working together in mathematics, students gain understanding and confidence when they work together to solve problems that can be solved with different strategies:

> Teacher 5: We gain effective learning experiences and we gain an increase in understanding. I found quite often the children could explain their thinking and strategies better than I could have. They are amazing to watch and listen to when they are helping each other and working together. They provide insightful interpretation to problems and they are usually very comfortable talking in small group to each other than in front of the whole class. This helps to improve confidence also.

Indications of teachers' belief in the process included their willingness to try any problems with their students, eagerness to see what their students would do with the problems, and statements that student success manifested itself in different forms. The distinction between the 26 teachers who strongly demonstrated their belief in the problem-solving process and the 15 teachers who partially showed this belief was the consistency of their actions and words. One example that illustrated a teacher showing partial belief occurred when the teacher appropriately used the problem-solving process for one problem but

identified the key relationship for the children during the presentation of the other problem. As another example, teachers characterized their in-class problem-solving experience as powerful and described the problem-solving process' key components, but when explaining their implementation decisions they indicated that not all students were capable of problem solving.

Conclusion

Teaching Elementary School Mathematics was a graduate course designed to facilitate teachers' learning to teach mathematics through problem solving. The research project examined teachers' actions and thoughts as they implemented action research projects based on problem solving as a way of knowing. Teachers' successes as they implemented a problem-solving approach provided evidence of teachers moving forward on their journey of learning to teach mathematics via problem solving. In support of other research findings (Borko et al., 2000; Brahier & Schäffner, 2004; Crespo & Featherstone, 2006; Kersaint & Chappell, 2001; Smith, 2000; Sullivan et al., 2009), this project found that teachers became comfortable with being a facilitator of student learning. Teachers maintained the integrity of the problems when presenting them, avoided the situation of modeling how to solve the problems, encouraged students to find ways to solve problems, and learned how to guide discussions as students explained their work. Teachers became more confident about their students' abilities to be problem solvers as students used different strategies to solve problems and demonstrated previously unseen strengths. Teachers learning about their students' potential and then expecting more from their students aligns with results found by Borko et al., Crespo & Featherstone, Kersaint & Chappell, and Smith.

The challenges teachers encountered illustrated the complex nature of professional development and teacher change. As teachers attempted to implement a problem-based instructional approach, often conflicting actions occurred. Teachers successfully used a problem-solving approach with one problem but not with the other. Teachers had their students work in groups for one problem but made group work optional for the other problem. Other teachers used group settings for both problems but told children which strategy to use to solve the problem. Some teachers recognized the importance of facilitating student interactions but were not quite sure how to do this. Collectively, these examples illustrate other researchers' findings that teachers are challenged by giving up control and becoming a facilitator of student learning (Borko et al.; Crespo & Featherstone, 2006; Kersaint & Chappell, 2001; Smith, 2000). As found by Kersaint and Chappell, it was often teachers' comfort level with mathematics that led them to make decisions minimizing the problem-solving opportunities for their students. Interestingly, teachers' comfort level with the mathematics content varied depending on the problem they used. While a teacher may have been weak in one of the previously stated areas for both problems, no teacher was weak in all of the stated areas. Even in conflict, positive actions occurred.

As shown by their successes and challenges, teachers demonstrated that a short-term professional development opportunity in the form of a course provided a spark for moving them forward on their journey toward learning to teach mathematics through problem solving. In particular, the opportunity to take on an action research project was the catalyst for teachers' movement on this journey. For the professor, observed successes illustrated how teachers' descriptions and actions were more positive than those generated in previous research. The professor's commitment to engaging teachers in a two-part problem-solving action research project enabled teachers to see what mathematical learning was possible when students guided their own learning while negotiating a shared understanding. For one-third of the group that taught using the *Investigations* (Russell et al., 1998) or *Connected Mathematics* (Lappan et al., 1998) curriculum materials during that year for the first time, the action research project and resulting course discussions enabled them to better understand the curricula, which in turn generated positive feelings toward these materials.

What will happen as these teachers move forward to the next school year? Will the positive impact problem solving had on their students propel them to continue on their journey, or will their tentative feelings about the process drive them to fall back on a more traditional teacher-directed process of teaching skill? Will teachers continue to believe that their students can be successful problem solvers or will they go back to the belief that learning through problem solving does not work with their students? Will teachers continue to enrich students' learning experiences by having them work together or will they act upon the belief that

students should not work together because the "good-at-math" students will do all of the work? All of these questions remain to be answered as teachers step away from the research process and step back into their classrooms in the fall. Borko and her colleagues (2000) remind us that "for significant and lasting change to occur, both beliefs and practices must change" (p. 300). During the graduate class discussions, teachers saw the results of changing their practices as they celebrated their students' successes. The following final teacher reflections suggest that teachers' beliefs have changed and give hope that these teachers will continue on their journey of learning to teach through problem solving.

> Teacher 21: The most meaningful experience was watching one of my students with the Shuffling a Line problem. He is not a top student, nor very confident. He was able to get the answer first and have the confidence and courage to share the process with everyone else. It really showed that if he can do it anyone can.

> Teacher 19: The most meaningful experience was the 1st dog problem! I had no clue/idea how or where to go with the problem. I couldn't even figure out that the name belonged to the dog!! *But*, it put me in my students' shoes and really made me understand how they might feel. . . . It was so powerful that such a little experience like that made me view the last month of school differently.

> Teacher 11: The most meaningful experience for me was looking at the problem solving aspect. My students could really benefit from using this format. I have planned to do more problem solving next year with my kids than I have in the past.

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PROBLEMS section

Ted Eisenberg, *Section Editor*

This section of the journal offers readers an opportunity to exchange interesting mathematical problems and solutions. Please send them to Ted Eisenberg, Department of Mathematics, Ben-Gurion University, Beer-Sheva, Israel or fax to: 972-86-477-648. Questions concerning proposals and/or solutions can be sent e-mail to eisenbt@013.net. Solutions to previously stated problems can be seen at http://ssmj.tamu.edu.

Solutions to the problems stated in this issue should be posted before February 15, 2011

5134: *Proposed by Kenneth Korbin, New York, NY*

Given isosceles ΔABC with cevian CD such that ΔCDA and ΔCDB are also isosceles, find the value of

$$\frac{AB}{CD} - \frac{CD}{AB}.$$

5135: *Proposed by Kenneth Korbin, New York, NY*

Find a, b, and c such that

$$\begin{cases} ab + bc + ca = -3 \\ a^2b^2 + b^2c^2 + c^2a^2 = 9 \\ a^3b^3 + b^3c^3 + c^3a^3 = -24 \end{cases}$$

with a < b < c.

5136: *Proposed by Daniel Lopez Aguayo (Student, Institute of Mathematics, UNAM), Morelia, Mexico*

Prove that for every natural n, the real number

$$\left(\sqrt{19} - 3\sqrt{2}\right)^{1/n} + \left(\sqrt{19} + 3\sqrt{2}\right)^{1/n}$$

is irrational.

5137: *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

Let a, b, c be positive numbers such that $abc \geq 1$. Prove that

$$\prod_{cyclic} \frac{1}{a^5 + b^5 + c^2} \leq \frac{1}{27}.$$

5138: *Proposed by José Luis Díaz-Barrero, Barcelona, Spain*

Let $n \geq 2$ be a positive integer. Prove that

$$\frac{n}{F_n F_{n+1}} \leq \frac{1}{(n-1)F_1^2 + F_2^2} + \cdots + \frac{1}{(n-1)F_n^2 + F_1^2} \leq \frac{1}{n}\sum_{k=1}^{n} \frac{1}{F_k^2},$$

where F_n is the n^{th} Fibonacci number defined by $F_0 = 0$, $F_1 = 1$ and for all $n \geq 2$, $F_n = F_{n-1} + F_{n-2}$.

5139: *Proposed by Ovidiu Furdui, Cluj, Romania*

Calculate

$$\sum_{n=1}^{\infty}\sum_{m=1}^{\infty} \frac{\zeta(n+m)-1}{n+m},$$

where ζ denotes the Riemann Zeta function.

558008

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Statement of Ownership, Management, and Circulation (All Periodicals Publications Except Requester Publications)

1. Publication Title	2. Publication Number	3. Filing Date
School Science and Mathematics	4 8 4 _ 1 2 0	10/1/10
4. Issue Frequency	5. Number of Issues Published Annually	6. Annual Subscription Price
Monthly except Jun, July, Aug, Sep	8	$227.00

7. Complete Mailing Address of Known Office of Publication *(Not printer) (Street, city, county, state, and ZIP+4®)*

Wiley Subscription Services, Inc., 111 River Street, Hoboken, NJ 07030

Contact Person: E. Schmidichen

Telephone *(Include area code)*: (201) 748-6346

8. Complete Mailing Address of Headquarters or General Business Office of Publisher *(Not printer)*

Wiley Subscription Services, Inc., 111 River Street, Hoboken, NJ 07030

9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor *(Do not leave blank)*

Publisher *(Name and complete mailing address)*

Wiley Subscription Services, Inc., 111 River Street, Hoboken, NJ 07030

Editor *(Name and complete mailing address)*

Gerald Kulm, TAMU 4232, Texas A&M University, College Station, TX 77843

Managing Editor *(Name and complete mailing address)*

Heather Lee, TAMU 4232, Texas A&M University, College Station, TX 77843

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Full Name	Complete Mailing Address
School Science and Mathematics Association	Oklahoma State University College of Education 245 Willard Stillwater, OK 74078

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☐ Has Not Changed During Preceding 12 Months

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PS Form **3526,** September 2006

13. Publication Title	14. Issue Date for Circulation Data
School Science and Mathematics	October 2010

15. Extent and Nature of Circulation			Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
a. Total Number of Copies *(Net press run)*			1328	1450
b. Paid Circulation *(By Mail and Outside the Mail)*	(1)	Mailed Outside-County Paid Subscriptions Stated on PS Form 3541 *(Include paid distribution above nominal rate, advertiser's proof copies, and exchange copies)*	955	974
	(2)	Mailed In-County Paid Subscriptions Stated on PS Form 3541 *(Include paid distribution above nominal rate, advertiser's proof copies, and exchange copies)*	0	0
	(3)	Paid Distribution Outside the Mails Including Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid Distribution Outside USPS®	0	0
	(4)	Paid Distribution by Other Classes of Mail Through the USPS (e.g. First-Class Mail®)	0	0
c. Total Paid Distribution *(Sum of 15b (1), (2),(3), and (4))*			955	974
d. Free or Nominal Rate Distribution *(By Mail and Outside the Mail)*	(1)	Free or Nominal Rate Outside-County Copies Included on PS Form 3541	18	18
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e. Total Free or Nominal Rate Distribution *(Sum of 15d (1), (2), (3) and (4)*			18	18
f. Total Distribution *(Sum of 15c and 15e)* ▶			973	992
g. Copies not Distributed *(See Instructions to Publishers #4 (page #3))* ▶			355	458
h. Total *(Sum of 15f and g)* ▶			1328	1450
i. Percent Paid *(15c divided by 15f times 100)* ▶			98.15	98.18

16. Publication of Statement of Ownership

☑ If the publication is a general publication, publication of this statement is required. Will be printed in the November 2010 issue of this publication. ☐ Publication not required.

17. Signature and Title of Editor, Publisher, Business Manager, or Owner	Date
Elizabeth Konkle, Associate Financial Manager	10/1/10

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Heather R. Rodriguez, Managing Editor
School Science and Mathematics Journal
Texas A&M University
4232 TAMU Harrington
College Station, TX 77843-4232

Circulation Data:

Reader: K-graduate leaders and teacher educators
Frequency of issue: 8 times per year
Copies per issue: 3001-4000
Sponsorship: Professional organization

Publication Guidelines:

Manuscript length, 6-25 pages, including references

Review Information:

Type of review: Blind review
No. of external reviewers: Three
No. of in-house reviewers: Up to three
Fees charged to review: None
Editor considers recommendations of reviewer: Yes
Time to review: 6-7 months
Reviewers' comments: Yes
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Enough information to enable replication (quantitative)

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